National Aeronautics and Space Administration

science & sports

Educational Product	
Educators and Students	Grades 5-8

Science and Sports
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National Content Standards

1. National Research Council
2. National Council of Teachers of Mathematics
3. International Technology and Engineering Education Association

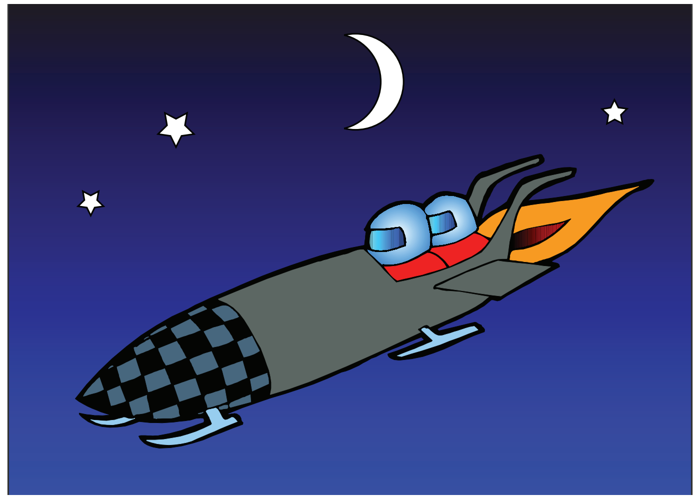
Standards	Hovering on a Cushion of Air	Center of All Things	Let's Do the Twist	Crazy Balloons	Javelin Rockets	Space Helmet Challenge
SCIENCE STANDARDS[1]						
Physical Science						
Motions and Forces • Understand motions and the forces that cause motion	●	●	●	●	●	●
Transfer of Energy • Understand ways in which energy is transferred • Understand the relationship between energy and force	●		●	●	●	●
Science and Technology • Abilities of Technological Design • Design a solution to a problem and evaluate its effectiveness	●			●	●	●
MATHEMATICS STANDARDS[2]						
Number and Operations • Perform operations with multi-digit whole numbers and with decimals to the hundredths	●				●	
Algebra • Write and interpret numerical expressions • Analyze patterns and relationships	●					
Geometry • Graph points on the coordinate plane to solve real-world and mathematical problems • Classify two-dimensional figures into categories based on their properties • Solve real-world and mathematical problems involving area, surface area, and volume	●	●	●	●	●	●
Measurement • Represent and interpret data	●	●	●		●	●
TECHNOLOGY STANDARDS[3]						
Design Standard 8. Students will develop an understanding of the attributes of design.	●			●	●	●
Standard 9. Students will develop an understanding of engineering design.	●			●	●	●
Standard 10. Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.	●			●	●	●

Hovering on a Cushion of Air

Pre-game Talk Show

If you have mixed feelings about friction, it's easy to understand. Friction is the force that resists motion when two objects are in contact with each other. It's both good and bad. Take cars, for example. Forget to check the oil and friction can ruin a car engine. However, without friction a car couldn't move. Tires are made from rubber, which produces friction with the road surface. When the wheels turn, friction enables the wheels to exert a force on the road to propel the car.

Reducing friction is important in many sports. Ice hockey depends upon the puck being able to slide across ice. Curling, a sport similar to shuffleboard but with heavy stones instead of pucks, also needs ice to slide across. Team members actually sweep the ice in front of moving stones to help reduce friction and guide the stones to the target. Bobsleds and luge sleds run down ice-covered chutes to achieve breakneck speeds. The chutes twist and turn. Runner blades on the sleds reduce downhill friction to attain high speeds while increasing sideways friction to help steer the turns.



Colorado Avalanche player Ryan O'Reilly applies Newton's Laws of Motion with his stick to smack (action) the puck across the rink (reaction).

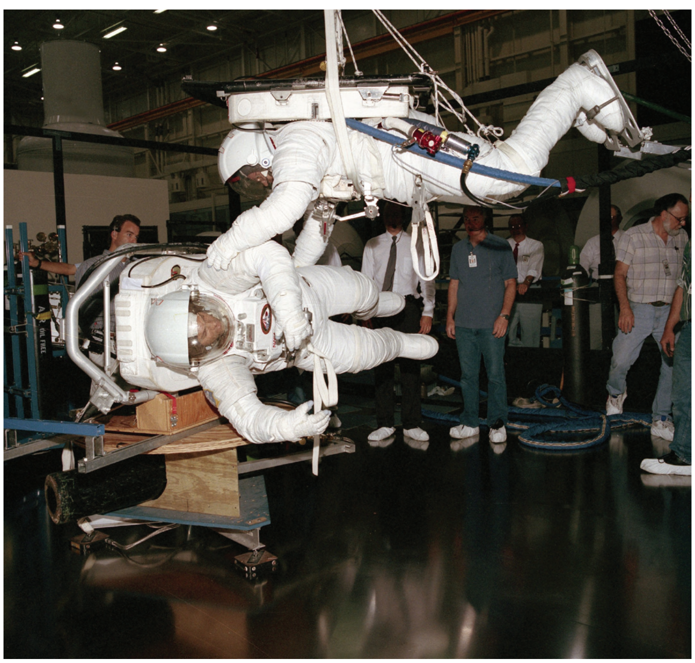
Reducing friction makes it easier to start objects moving. Isaac Newton's First Law of Motion explains why. The law states that objects remain still unless acted upon by unbalanced forces. In other words, if forces on an object are unbalanced, the object moves. What then is an unbalanced force?

To understand unbalanced forces, imagine what would happen if you and a friend were to push on each other with equal force. Neither of you would move because the forces are balanced. However, if one of you pushes harder than the other, movement takes place because now the forces are unbalanced. An ice hockey puck, for example, is resting on the ice. The ice surface is very slick but it still has a small amount of friction. When a player smacks the puck, the puck shoots across the rink. The force exerted on the puck by the stick is far greater than the force of friction trying to hold the puck where it is. Consequently, the forces are unbalanced, and the puck shoots away.

Newton's First Law of Motion also explains that an object in motion will travel in a straight line at a constant speed unless an opposing unbalanced force slows or stops it. In ice hockey, the goalie will try to exert an unbalanced force by blocking the puck. If the goalie misses, the goal net will exert the unbalanced force and stop the puck - score 1!

Understanding Newton's First Law of Motion is important for astronauts training for future space missions on the International Space Station (ISS). When in space, they will have to move objects and themselves from place to place. To do that, they need to exert unbalanced forces. But being in space is something like being on an ice rink on Earth. Try taking a quick step on an ice rink without wearing ice skates. With little friction, you are likely to end up on your backside!

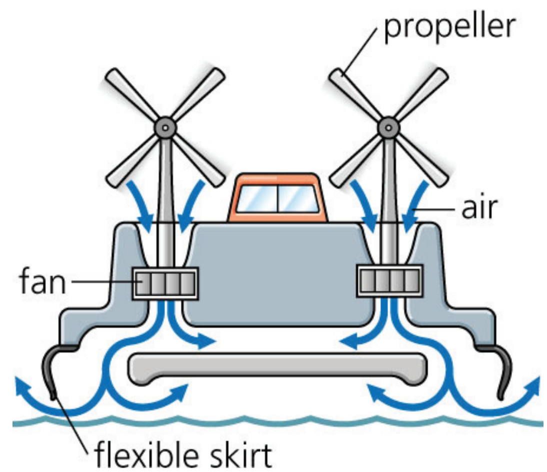
In space, friction is greatly reduced because of the microgravity environment. It feels like gravity has gone away. Of course, gravity is still there because gravity holds the ISS in orbit. But orbiting Earth is like a continuous fall where the spacecraft and everything inside falls together. The type of friction caused by objects resting on each other is gone. To move, astronauts have to push (exert an unbalanced force) on something, and to stop themselves, they have to push on something else.



Two astronauts practice space rescue over the Precision Air Bearing Platform (PABP) at the NASA Johnson Space Center. One astronaut is suspended from a crane but the other is riding on cushions of air. Beneath the small platform, the sideways astronaut is riding on three small pads that lift the platform with high pressure air shooting out from them. This nearly eliminates friction with the smooth floor and simulates microgravity.

How can astronauts practice for the microgravity environment on the ISS? NASA uses many different simulators to train astronauts. One simulator is something like a large air hockey table. It is called the Precision Air Bearing Platform (PABP) and is located at NASA Johnson Space Center in Houston, Texas.

The PABP uses moving air to produce a powerful lifting force very much the way hovercraft work. High-pressure air rushes out of three small pad-like bearings and lifts the pads, and a platform mounted above them, a fraction of a centimeter from the floor. No longer resting directly on the floor, the device, with the



What's a Hovercraft?
Hovercraft are vehicles used for carrying people and heavy objects over water and rough surfaces. Powerful fans, like airplane propellers, blow air downward. The air blast is caught by a skirt that lifts the craft above the surface before the air escapes to the sides under the lower edges of the skirt. This reduces friction with whatever surface over which the craft is hovering and enables it to be easily propelled by action/reaction with other fans mounted horizontaly.

astronaut on top, is virtually frictionless.

There is one more important feature of the PABP. In order to move across the floor, the astronaut has to push on something. Additional air is fed to small nozzles around the astronaut. The astronaut uses a hand control to release the jets of air in different directions to create a push. How much of a push the astronaut gets determines how fast he or she slides across the PABP floor. This is explained by Newton's Second Law of Motion. The force of the air jets is equal to how much air shoots from the jets times how fast the air accelerates. Newton's Second Law of Motion is really an equation.

force = mass times acceleration (F=m x a)

With the control jet, the more air shot from the jet and the faster it shoots out, the greater the force produced and the more the astronaut moves.

There is one more law of motion. This is Newton's Third Law of Motion. It is also called the action/reaction law. When a force is exerted (action), an opposite and equal force (reaction) is created. You can see this with rockets. Burning rocket propellants produce gas that shoots out of the engine. The rocket moves in the opposite direction. If you happen to be riding a PABP like the one at the NASA Johnson Space Center, you get to experience action/reaction first hand. The PABP greatly reduces friction and an air jet (action) propels you across the platform (reaction). Unless you exert a new action force in the opposite direction, you will smack into the wall surrounding the PABP.

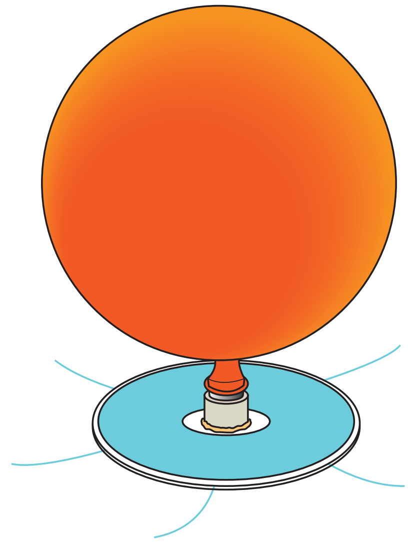
Analyze any sport or the movements of astronauts in microgravity, and you will see all three of Isaac Newton's Laws of Motion at work.

Hovering on a Cushion of Air

Objectives

Students will:

- construct CD hovercraft
- investigate how hovercraft reduce friction
- apply Newton's Laws of Motion to make hovercraft work
- understand how hovercraft technology is used in training astronauts space missions
- design hovercraft sporting events



Preparation:

Obtain the materials for constructing the hovercraft. Set up a hot-glue gun station for attaching PVC tubes to the CDs. Place a dish of cold water with a few ice cubes near the hot-glue station (See management tips.) Prepare a long, smooth surface such as a table top or a tile floor for testing and using hovercraft.

Materials: (per student or group)

- Old, unwanted compact disks (CDs)
- 1/2-inch-diameter PVC pipe segment, 3/4 inches long
- Round balloon (five-inch size)
- 3/4- or 1-inch gummed label dot
- One hole rubber stopper, No. 2 size

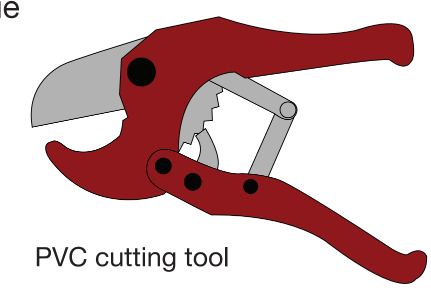
Materials: (per class)

- One or two low-temperature hot glue guns and glue sticks
- Eye protection
- Dish with cold water
- PVC cutting tool (optional) or fine-tooth saw
- Standard paper punch (approx. 1/4 inch hole)
- Meter stick
- Stopwatches or clock with second hand
- Meter sticks or tape measures
- Balloon air pumps (recommended)

Management Tips:

PVC pipe comes in 10-foot lengths but 5-foot lengths may also be available. One 10-foot pipe can be cut into enough pieces for about 150 hovercraft if a PVC cutting tool is used. The tool, a ratchet cutter similar to hand pruning shears, slices easily through PVC. A saw can also be used to cut the PVC, but it will produce "sawdust" and fewer pieces.

Set up a glue station with one or two glue guns. Be sure to use low-temperature glue guns. The heat from high-temperature guns may warp the CD. Having a dish of cold water near the glue station is a good safety step. If students get hot glue on their fingers, immersing the fingers in cold water will immediately "freeze" the glue and minimize any discomfort. If preferred, the teacher or a teacher's aide can operate the glue gun. Eye protection is recommended when working with glue guns.



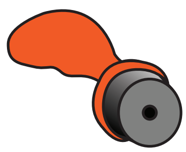
PVC cutting tool

Pop-up spouts for water bottles can be substituted for the PVC pipe and rubber stopper. Remove the cap from the bottle and attach it to the upper side of the CD with hot glue. Fit the balloon over the pop-up spout. Inflate the balloon by blowing through the underside of the hovercraft and push the spout down to hold the air until ready. Pull up on the pop-up spout to release the air and launch.

If you have any student with a latex allergy, wash the balloons before using. Have allergic students wear non-latex plastic gloves and inflate the balloons with a balloon pump (or form small teams and give the balloon handling part of the activity to non-allergic students).

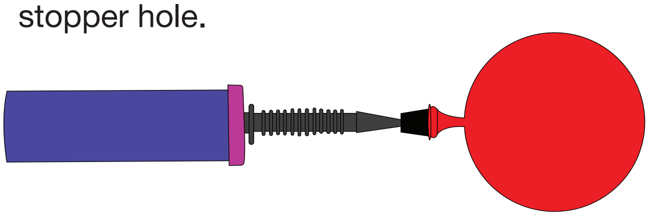
Procedure: Assembling the hovercraft

1. Squeeze a bead of hot glue on the edge of one end of the PVC pipe and immediately press the glued end to the center of the CD (label side up). The pipe will surround the hole in the center of the CD.
2. When the glue has cooled and hardened (in about 1-2 minutes), check for any gaps between the CD and pipe. If there are any, squeeze some glue in to fill the gaps.
3. Stretch the latex balloon a couple of times to relax it for inflating.
4. Stretch the balloon nozzle over the wide end of the rubber stopper.
5. Use a hole punch and punch a hole through the center of the gummed paper dot. Apply the dot to the underside of the CD to cover the hole. The hovercraft is finished.



Procedure: Running the hovercraft

1. Inflate the balloon by either blowing through the hole of the stopper or by inserting the nozzle of a balloon hand pump into the stopper hole.



2. Twist the balloon so that the nozzle is closed off and press the small end of the stopper into the upper end of the PVC pipe in the hovercraft. The hovercraft is ready to launch.
3. Place the craft on a smooth, level surface such as a tabletop. Release the balloon. It will untwist and start blowing air downward through the small hole in the center. The thin cushion of air will lift the CD and eliminate friction with the tabletop.
4. Have students try pushing the hovercraft across a tabletop with the balloon inflated and again with it uninflated. Compare the craft's movement in the two runs.
5. Allow students to experiment with the optimum size of the hole in the paper dot. The hole can be enlarged by pushing the point of a pencil into it. The hole size will determine how fast the air runs out. Provide more dots for students to try.
6. Have students record their data on the Hovercraft Challenge student pages.

Assessment:

Collect and review the Hovercraft Challenge student pages. Use the following questions for a review discussion or have students write short paragraph answers.

Discussion Questions:

What causes the hovercraft to become frictionless? Explain.

Air from the balloon escapes beneath the hovercraft. It forms a thin cushion that lifts the craft a few millimeters above the table. Without direct contact with the tabletop, friction is greatly reduced.

What happens to the hovercraft's movement when the balloon runs out of air? Why?

When the balloon runs out of air, the lifting cushion stops. The full surface of the CD bottom contacts the tabletop, friction is greatly increased, and the hovercraft stops.

How do different surfaces affect the hovercraft?

Smooth surfaces permit a uniform cushion of air to lift the craft. Rough surfaces allow air to escape more in some directions than others and the craft is no longer level. Parts of the CD touch the surface and cause drag.

How does the size of the paper dot hole affect the hovercraft?

The hole controls the flow of air from the balloon. If the paper is removed, the hole is very large and the air escapes quickly. A tiny hole greatly slows the flow of air and may not provide enough lifting force. Through experimentation, the best hole size is _______ (student answer).

Explain how Isaac Newton's Laws of Motion control the movement of the hovercraft.

1. An unbalanced force is needed to lift the craft. Another force is needed to propel the craft along the table.
2. The lifting force is determined by how much air is released (its mass) and how fast it accelerates out of the hole.
3. The action force of the air released from the balloon creates a reaction force lifting the hovercraft. Pushing on the hovercraft to cause it to move along the tabletop is also an example of action and reaction.

How can hovercraft technology be used to simulate microgravity when training astronauts?

The picture of the astronauts at Johnson Space Center (Page 10) illustrates a training technique using air bearing pads on a very smooth floor. Three air bearing pads, similar in size and identical in function to the CD hovercraft, produce great lifting force and nearly eliminate friction. The bearing pads are able to provide much greater lifting force than the CD hovercraft because high pressure air from compressors is used. When the two astronauts push on each other, they fly apart in a great demonstration of Newton's Laws of Motion.

Extensions

- Have students try their hovercraft on different surfaces (tabletop, tile floor, carpet, sand, etc.). On which surfaces does the craft work and on which doesn't it work? Why?
- Investigate the size of the hole in the paper dot. What hole size works best to keep the craft aloft the longest? (The hole size can be enlarged by pushing a pencil tip into it and spreading the paper.)
- Have students investigate how much mass their craft can lift. Small paper clips have an approximate mass of 2 grams. How many paper clips (or metal washers, pennies, etc.) can their craft hold and still move across a tabletop?
- Have students create sporting events for their hovercraft. Some ideas for events might include:

  - "Kick" field goals by shooting hovercraft between two water bottles down field.

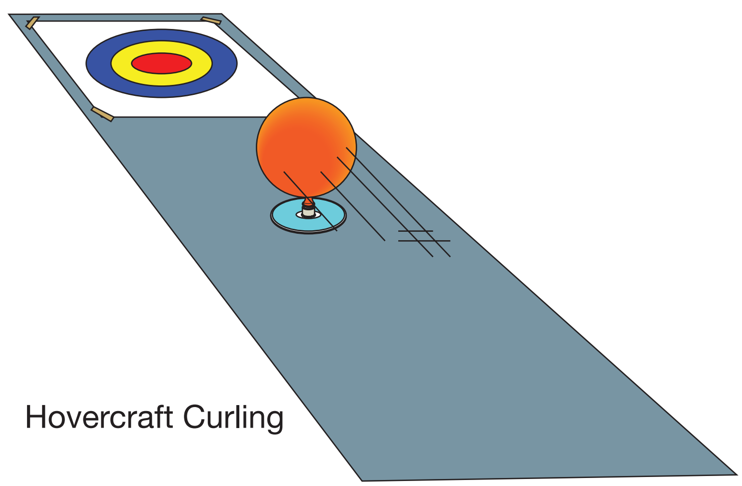
  - Make a net for soccer goals.

  - Play hovercraft curling by using balloon pumps or small paper fans students construct to move the hovercraft and have it stop in the bull's-eye of a target at the other end of a table.

  - Hovercraft drag racing (which craft reaches the finishing line first).

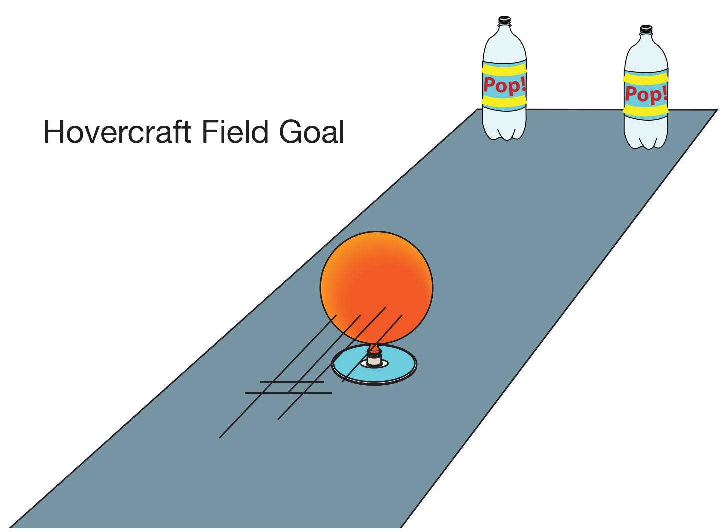
  - Hovercraft shot put. Go for distance.

  - Hovercraft bowling. Aim at lightweight pins made from notebook paper rolled and taped into tubes.



Hovercraft Curling

Hovercraft Field Goal



Hovercraft Challenge

Name: ____________________

Challenge - Distance

How far can you make your hovercraft travel before it stops on its own? Try three times.

First Run Distance in cm	Second Run Distance in cm	Third Run Distance in cm	Average Distance in cm

What did you do to try to increase your distance? Did it work?

Challenge - Time

How long can you make your hovercraft hover before it comes to a rest on its own? Try three times.

First Run in seconds	Second Run in seconds	Third Run in seconds	Average Time in seconds

What did you do to try to increase your time? Did it work?

Challenge - Speed

How fast can you make your hovercraft move? Measure distance and time. Try three times.

First Run	Second Run	Third Run
cm / sec	cm / sec	cm / sec

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \_\_\_\_\_ \text{ cm/sec}$$

First Run speed in cm/sec	Second Run speed in cm/sec	Third Run speed in cm/sec	Average Speed in cm/sec

What did you do to try to increase your speed? Did it work?

Hovercraft Challenge

Name: ____________________

Create an Olympic sport for your

Challenge others to compete for the Interplanetary cup.

Describe your sport:

What is its objective?
What happens when you play your sport?
What does your playing field look like?
How many teams compete?

What are the rules:

How is the game scored:

How do Isaac Newton's Laws of Motion apply to your sport?
Could your sport be played on the International Space Station? On the moon? On Mars?

Use the other side of this page for your answers.

I Do the Shimmy When I Fly Through the Air Part One

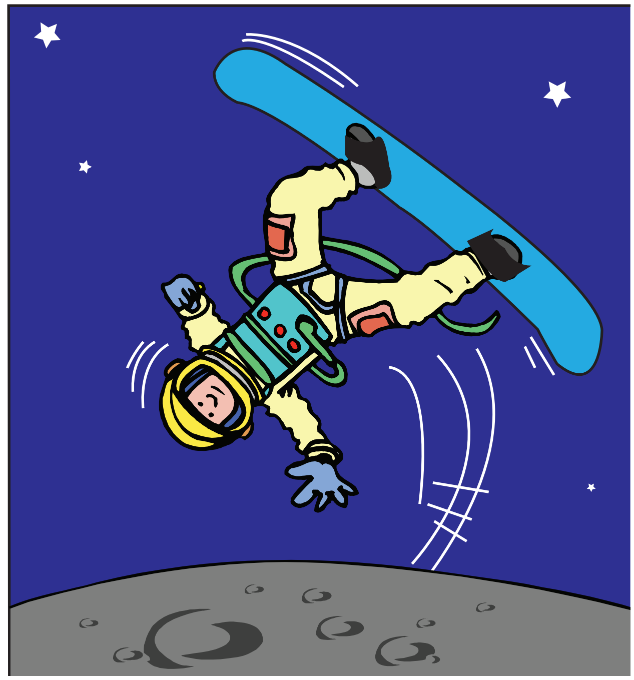
Pre-game Talk Show

How do they do that? If you watched the snowboarders run the half-pipe during the Winter Olympics, you probably want to know. The killer aerials performed on the half-pipe are amazing. (Oops! Just said something twice: “killer” = amazing, “aerial” = a cool trick in the air.) Like every sport, snowboarders have their own slang to describe everything from their gear to their aerials to their crashes (“yard sale” is a snowboarder’s gear, hats and/or gloves that end up scattered on the slope).

When you listen to TV commentators describing the performances, you hear lots of oohs and aahs and remarks about artistry in the air. True, there is artistry, but the real secret of snowboarding is science!

Snowboarding has a lot in common with other sports. In fact, snowboards were inspired by skateboards, surfboards, and skis. These three sports depend upon reducing friction (science). Like skis, snowboards ride the low-friction snowy slopes. Like surfing, snowboards are made of a single board, but snowboards are attached to the feet with ski bindings. Like skateboarders, snowboarders can perform killer aerials (nollies, doublechuks, fakies, rocket airs, McTwists, tame dogs, misty flips, etc.) using a U-shaped snow structure called a half-pipe similar to that found in a skateboard park.

Catching some serious air, this snowboarder has gained enough momentum to perform some killer tricks!

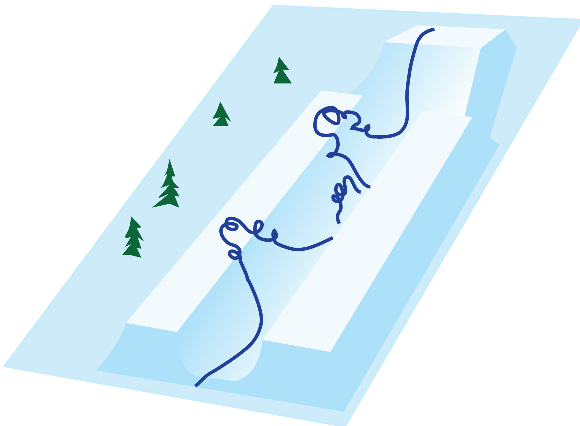


A half-pipe is a wide U-shape channel with steep sides that stretches between 100 and 150 meters down a steep hill. Above the half-pipe is a small snow ledge or platform where the snowboarder sets up and creeps to the edge. Just below the platform is a drop-in ramp (steep slope) that aims and accelerates the snowboarder toward the half-pipe.

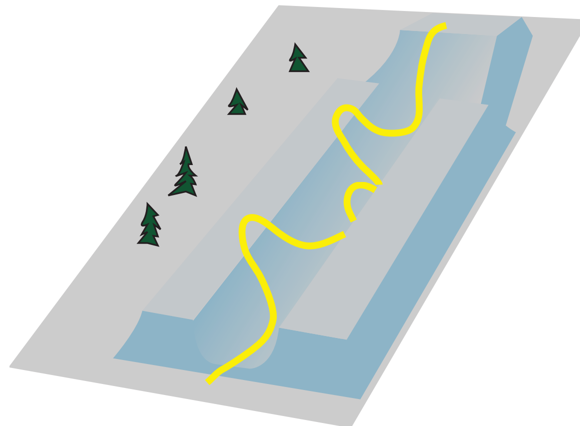
A snowboarder leaps down the ramp and shoots into the half-pipe. The energy to do so comes from gravity. Gravity causes the snowboarder to accelerate (go faster and faster). At the right moment, when enough speed has built up, the snowboarder leans to one side or another, cuts into the snow with the board edge and blasts up the half-pipe side.

The snowboarder’s momentum (the product of the snowboarder’s mass times velocity) sends the snowboarder airborne. That’s when the fun begins. The snowboarder executes a couple of great tricks - turns, twists, flips - and then drops down the half-pipe side, to gain momentum for shooting up the other side.

Each maneuver carries the snowboarder farther down the half-pipe. Then comes the final



Daytime snowboarder showing twists and turns of the aerial path.



Nighttime snowboarder run showing center of mass path.

aerial, with the most spectacular tricks ending in a great landing with only the board touching the snow (or so that is the plan). The more difficult the aerial and the better the landing, the more points the snowboarder gets.

As you might guess, there is still more science involved in snowboarding. Gravity provides the kinetic (motion) energy and momentum enables the air time, but where do the twists and turns come from?

First, think about the actual path the snowboarder follows down the half-pipe. If we could send a snowboarder down the slope in complete darkness except for a light bulb near the snowboarder's waist, something interesting would be seen. The light streak would be a very smooth line with turns and bumps but none of the circles or loops or jags we see when the lights are on. That's because all the tricks occur around the snowboarder's center of mass (also called center of gravity).

The center of mass is the average location of all of the mass in a body. Pick up a pencil and balance it horizontally on your finger. When the pencil is balanced, its center of mass will be directly above your finger. That's the only place in the pencil that will enable it to balance horizontally. Sharpen the pencil, and the center of mass will move towards the eraser end. Less mass on the pencil tip end moves the center of mass towards the other end.

The next activity will challenge you to locate the center of mass of an object with a very unusual shape. As you will see, there's always a way to find the "Center of All Things."

Center of All Things

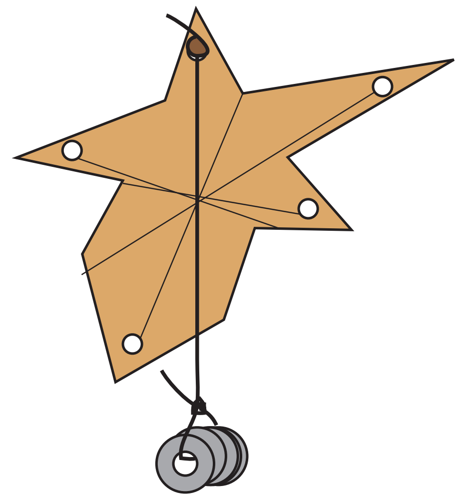
Objectives:
Students will;
- use gravity to locate the center of mass of irregular-shaped objects
- define the center of mass of an object as the average location of all of the mass contained in that object
- balance an object by supporting it under center of mass

Preparation:
Cut one cardboard shape for each team of two or three students. Follow the instructions in the procedures. Create plumb lines and bobs by tying 50-cm strings to the middle of the short sticks and tie five washers on the other end of the string.

Materials: (per team of students)
- Prepared cardboard "stars" (see procedure)
- Five metal washers (3/8 or 1/2 inch)
- Strings
- Short stick (10-cm-long piece of wooden skewer, small-diameter wood dowel, or straight drinking straws)
- Paper punch
- Student sheets

Management Tips:
Organize students into cooperative teams of two or three. Save class time by preparing plumb lines and bobs in advance. If time is available, have student teams create their own.

Procedure:
1. Cut out irregular shapes of corrugated cardboard, approximately 30-40 cm across. Use copy paper boxes or cardboard from other boxes, and make each piece look like a misshapen star. Make each star different.
2. Using the paper punch, punch one hole in the tip of each star point.



3. Tie five washers to the end of strings to make plumb lines. The washers serve as plumb bobs. (Plumb lines are strings with weights used in surveying and construction for creating a vertical line.) Tie a small loop at the other end of the string for suspending on the stick.
3. Provide teams with a star, plumb line with washer bob, and a short stick.
4. Demonstrate how to balance the star by inserting the stick through any of the holes and allowing it to hang. Gravity will cause the star to hang so that exactly half its mass hangs to one side of the stick and the other half to the other side. Suspend the bob from the stick and carefully draw a light pencil line on the cardboard along the string. Ask your students to predict what will happen if you move the stick to other holes and repeat the steps.
5. Have students follow the student sheet procedures.
6. Discuss what the student teams learned about center of mass.
7. Give students new stars and have them predict where the centers of mass are located. Then have the teams check their predictions with the plumb lines.

Assessment:

Have students fill out their student sheets and review their entries.

Check to see if student teams have correctly determined the center of mass of the stars. Ask one member of each team to balance the star on a fingertip. The fingertip should go directly beneath the intersection of the lines. If drawn accurately, the star will balance.

Hold up various objects and ask them to speculate where the center of mass for each object is. (E.g., The center of mass of a hula hoop will be in the middle of the air space surrounded by the hoop. The center of mass of an object doesn't have to be inside the object itself. Show how the hula hoop rotates around its "air" center of mass by tossing it into the air while it is spinning.)

Discussion Questions:

Do you have a center of mass? Where is it?

When standing straight, your center of mass will be along a perpendicular line stretching from the head, straight through your body to the floor. Because of differences in distribution of fat and muscles, the center of mass for boys tends to be higher along the line than the center of mass for girls.

Why is center of mass important for astronauts?

During spacewalks, an astronaut needs to move. All movement will take place around the astronaut's center of mass. If using a propulsion device like Ed White's hand-held maneuvering unit (gas gun), the gas thrust has to be in direct line with the body's center of mass (Page 31). If not, the astronaut will spin out of control. Also, remember the astronaut is wearing a bulky spacesuit that has mass too. Modern spacewalking propulsive units are usually worn around backpacks. They have multiple gas nozzles and several fire at the same time to bracket the center of mass and enable precise maneuvers.

Extensions:

• Place a heavy book on a smooth tabletop. Using just one finger, push on the book binding to move it across the table. If the book moves in a straight line, you are pushing in line with the book's center of mass. If you are pushing away from the center of mass, the book will rotate.

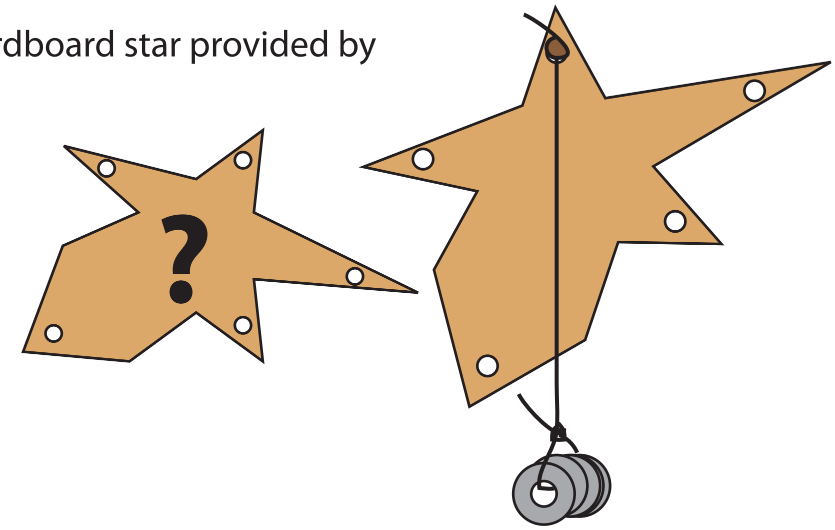
• Place a heavy object like a small barbell weight plate or a heavy book in a copy paper box to one side of the center. Close the box. Have students try to locate the center of mass of the box by pushing on it in different places. (Note: Even though most of the box is filled only with air, the entire box has a center of mass. The center will be near the weight.)

• Set up a boys-against-girls challenge. Place a folding chair sideways to the wall. Have a student stand facing the wall but positioned so that his or her feet are not under the chair. Tell the student to bend over at the waist and touch his or her forehead against the wall while keeping the back straight. Challenge the student to lift the chair and stand up without moving his or her feet. Be prepared to catch the boys! The center of mass for boys is higher than for girls. A boy's center of mass will extend over the chair, making it impossible for him to stand up without pulling away from the wall. A girl's center of mass in closer to her hips. Even when bent over, her center of mass is still over her feet, so she can lift the chair and stand.

Center of All Things

Name: ______________________

Where is the center of mass of the cardboard star provided by your teacher? How can you find out?



Instructions:

1. Gather the following materials:
   Cardboard star
   String with washers attached
   Small stick
   Pencil

2. Insert the stick through one of the holes in the star points. Let the star hang freely.

3. Hang the loop of the string on the stick so that the washers dangle below.

4. While keeping the star and string still, draw a straight pencil line across the star right next to the string.

5. Repeat steps 2 through 4 for the other star points. What happened to all the lines you drew?

6. Where do you think the center of mass for your star is located. Explain why you think it is in this location.

7. Write a definition for center of mass.

8. The star is flat. How would you determine the center of mass of an object that is three-dimensional (like a box, ball, or an astronaut)? Explain your idea. Use the back if you need more space for your answer.

I Do the Shimmy When I Fly Through the Air Part Two

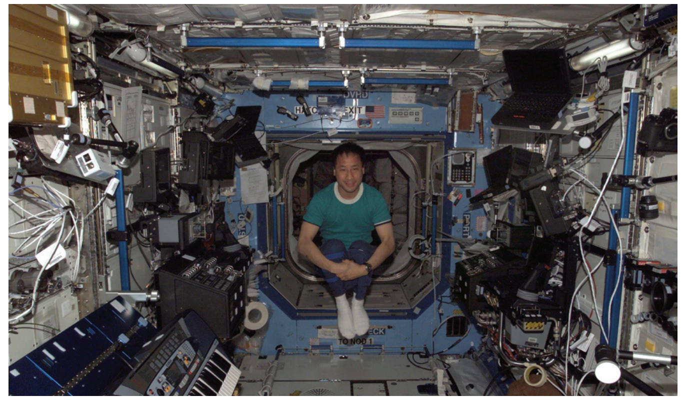
Half-time Talk Show

We all have a center of mass in our bodies. When snowboarders perform aerials, they rotate around their centers of mass. That's why a light on a snowboarder, performing in the dark, would inscribe a curved but smooth line. The snowboarder's tumbling body parts are just rotating around and following the center of mass down the half-pipe slope.

How then does the snowboarder achieve the intricate tricks? Again, it's a matter of science. While in the air, the snowboarder twists and turns body parts. The head is thrown back or forward, knees brought to the chest or extended, arms tucked in or shot out, the waist twisted (sometimes all this at the same time). These movements, driven by muscle power, cause the body to rotate around the center of mass.

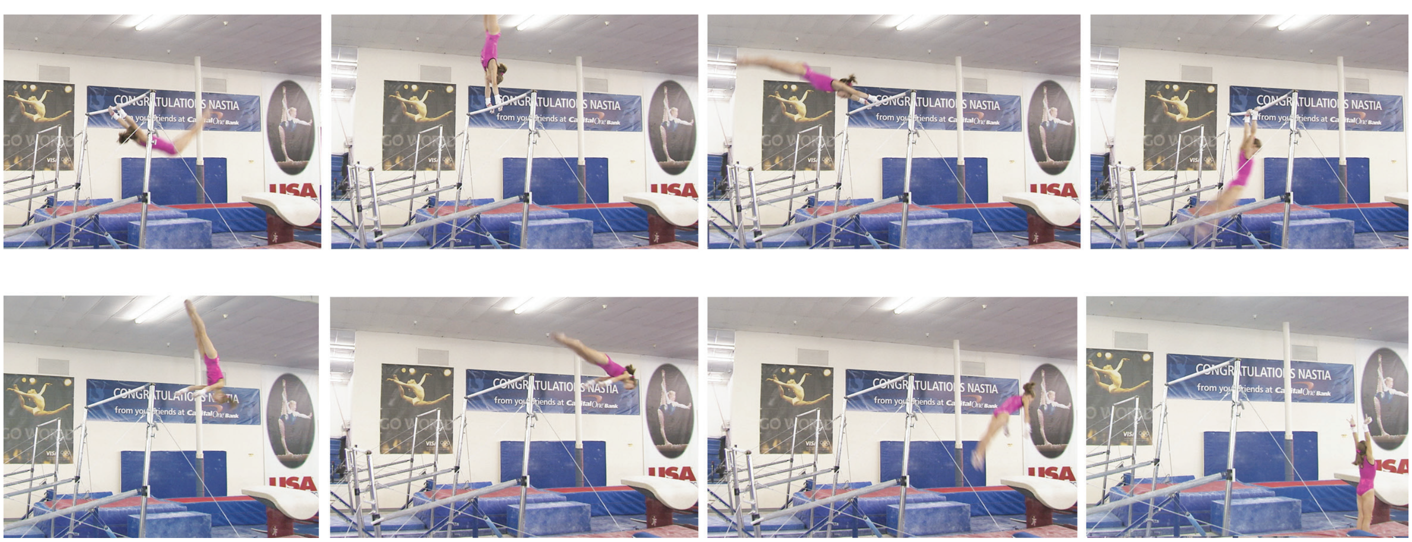
Back to the balanced pencil. Using your other hand, give a sharp flick to one end of the pencil. The pencil will tumble end over end through the air but always rotate around the center of mass you located.

Even though a snowboarder's body is not rigid like a pencil, sharp body movements on one side of the center of mass are balanced by sharp body movements on the other side. When the snowboarder finally stops twisting or tucking (so they can land their trick), the rotations stop, hopefully with the snowboard positioned beneath to land on the snow.



Astronaut Ed Lu doing an "aerial" on the ISS.

All the twists and turns in flight are governed by the snowboarder's moment of inertia. We've learned that inertia is the resistance of an object to change its motion (Newton's First Law). Moment of inertia is the law applied to rotating objects. When a snowboarder goes airborne, the muscle-driven body movements exert a force that causes rotation. How fast one rotates is determined



Unlike the astronaut on the ISS who has to push on a wall to start tumbling, the gymnast takes advantage of gravity to build up amazing speed as she rotates on the bar and prepares for a successful dismount.

by how tight the body is. When arms and legs are drawn into a tuck, the rotation is very fast. When they are spread out, the rotation slows or stops, depending on how quickly the movement takes place.

Moment of inertia is especially easy to see in another winter sport - figure skating. When skaters want to spin in place, they swing their extended arms to start the spin, then bring them into a tight hug. Legs come in, too. That speeds up the rotation rate. Extending the arm and legs out slows the spin.

A gymnast can achieve amazing rotational speed while tumbling in the air during floor exercises or dismounting from the parallel bars. Rotation speed increases as the body (mass) is tucked tighter, decreasing the axis of rotation.

Would you like to try spinning like an ice skater? The next activity, “Let’s Do The Twist,” will show you how - no skates required!

Let's Do the Twist

Objectives:
Students will:
- perform "aerials" on a swivel office chair
- investigate the principle of conserving angular momentum

Preparation:
Clear an area in your classroom so that volunteers on the chair will be able to sit with arms and legs extended and not hit any objects or fellow students.

Materials:
- Swivel office chair
- Two hand weights two or three pounds each
- Bearing platform (optional - see special instructions)
- Large plastic five-gallon hardware store bucket (optional)

Management Tips:
Select an office chair with a free-moving swivel. An adjustable artist stool will also work. It is important that it turns freely when spun. It is also best that the chair be set in a clear area on a hard, uncarpeted floor. When doing the second part of the activity, start slow to help students retain their balance.

Procedure: Aerials on an office chair

1. Ask students if they have ever watched acrobatic-type sporting events in person or on TV. With student help, create a list of these events on the board. Acrobatic-type sporting events include those in which contestants perform maneuvers with their bodies, usually while airborne. The list might include:
   - Snowboarding
   - Platform diving
   - Skateboarding
   - Figure skating
   - Gymnastics
   - Trampoline
   - Etc.

   Discuss what these events have in common. Ask if students think these events would work in the microgravity environment of space.
2. Select a volunteer for a demonstration. Place the volunteer on the swivel office chair and challenge him or her to try to move the chair across the room without touching the floor or any other object with their hands or feet. The student will be able to twist and rock and even turn the chair around but will not be able to move across the room. When the student stops moving, so will the chair.
3. Ask other students to make observations about the movements and the progress of crossing the floor.
4. If time permits, allow other students to demonstrate the activity.

Assessment:
Have students answer the questions on the activity sheet.

Discussion Questions:
Around what point is the student on the chair turning?
The student is turning around the combined

Astronaut Bruce McCandless flies the manned maneuvering unit during a 1983 spacewalk. The unit, resembling an easy chair, has posts above the shoulders and near the knees. Each contain clusters of gas jets for maneuvering in space.

center of mass of the chair and the student's body. The bearing of the chair tends to be close to this point and rotation occurs around it.

Why does the chair stay put?

Because of the bearing beneath the chair seat and the casters on the chair feet, friction with the floor is very low. The volunteer is not able to exert a sufficient force on the floor to move across the room. Without an action/reaction force (Newton's Third Law of Motion), it is not possible to move across the floor. (Note: Sometimes, one or more chair casters are worn and "grab" the floor in some directions, causing small jerking movements that leads to small movements from the initial place. With all casters working well, the chair stays over the same place.)

What would happen to an astronaut on a spacewalk if the astronaut forgot to attach to the ISS and drifted out of reach of the structure?

The astronaut would be unable to get back to the station and become a separate "satellite" circling Earth.

Extensions:

- Ask students to design a piece of equipment that could be used to bring an astronaut back to the ISS should the astronaut get loose and be drifting in space. Have students diagram their ideas and explain them to the class.
- Have students create an Olympic acrobatic event for inside the ISS. How would the event be played, what equipment could be used, what aerials could be performed, how would points be scored, etc.?

Procedure: Conserving angular momentum (Note: This activity can be done with the same office chair used for the previous activity. However, many schools use bearing platforms available from science supply catalogs. These platforms spin more freely than office chairs, producing a better rotating effect. Refer to the next page for instructions on constructing a very smooth but rugged platform using an automotive bearing.)

1. Place a student on the swivel office chair or a bearing platform (with an upside-down bucket for a seat).
2. Give the student two hand weights, and tell the student to extend his or her arms.
3. Spin the student slowly. On command, have the student bring the two weights to his or her chest. The student's rotation rate will

dramatically increase. Tell the student to extend the weights again, and the rotation rate will decrease.

Assessment:

Discuss student observations of what happened when the weights were extended, brought inward, and extended again.

Discussion Question:
Does the spinning student speed up when the weights are brought inward? Explain.

No. Except for a minor slowing due to bearing friction, there wasn't any change in speed. Speed is the distance an object travels over a unit of time, such as meters per second. Instead, what did change was rotation rate, which is measured in revolutions per unit of time.

For discussion's sake, let's say that the weights, when extended, follow a circle that has a circumference of five meters. When the weights are brought inward, the circle has a circumference of one meter. Finally, let's say that you start the student rotating, with weights extended, at a rate of one rotation per second. (Of course, this is a very fast rotation rate but using whole numbers makes it easier to understand what is happening.) During a single rotation, the weights will travel a distance of five meters. Their angular velocity is five meters per second. When the weights are brought inward, the rotation rate increases to five times per second, but with a circumference of one meter, the weights are still traveling five meters per second! When the weights go back out, the rotation rate drops but not the angular velocity.

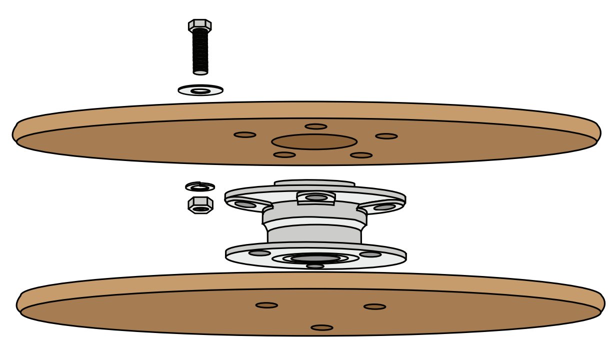
Extensions:

- Obtain videos of Olympic and world championship winter events - figure skating, snowboarding, gymnastics, etc. Have students try to track the center of mass of snowboarder aerials and observe and analyze fast spins on the ice.
- Have students calculate the angular velocity and rotation rate for chair volunteers. They will need a meter stick and a stop watch. Measure the radius of the weights with arms extended and arms brought inward. Calculate the circumference for both radii. Time the rotation rate with arms extended and predict what the rotation rate will be when arms are brought inward.

Procedure: Constructing a bearing platform

By necessity, these instructions will be less than detailed. You will need to obtain a hub bearing from an automotive supply store. The particular bearing will determine the number, size, and length of the bolts needed. Take the picture below to the parts store and have the clerk pick a bearing that most closely matches the illustration.

Pre-cut and sanded wooden disks shown in the illustration are available from a lumber/hardware store. Disks about 16 or 18 inches across are perfect. Three-quarter-inch plywood can also be used. Purchase bolts, washers, and lock washers to match wood thickness and bearing holes. Drill appropriate size holes and assemble. To reduce slipping, glue carpet on the outside surfaces of the wood disks. If this seems like too much for you to do, you probably know someone or there is a parent from the school parent association who can construct the platform for you. The platform will last for years.



Let's Do The Twist

Name: ____________________

1. Describe what happened when someone twisted in the seat of the swivel office chair.
   Was the person able to turn the chair around without touching feet to the floor?

   Why or why not? Explain scientifically what took place.

2. What happened when someone tried to move the swivel office chair across the room?
   Did the chair move from its original position?

   Why or why not? Explain scientifically what took place.

3. Around what point is the chair turning? Explain.

4. Describe what happened when the person rotating in the swivel office chair extended weights outward and then brought them inward?

   Explain scientifically why this happened.

5. Working with group members, create an Olympic acrobatic event for inside the International Space Station. Use the back of this paper to describe your event. Feel free to draw pictures to help visualize the event and the equipment needed.

   - What would the space acrobats do?
   - What equipment would be needed for the event?
   - What aerials could be performed?
   - How would the performance of the athletes be scored?

I Do the Shimmy When I Fly Through the Air Part Three

Edward H. White, Jr. on 1965 spacewalk. The gas propulsion gun in his right hand.

Post-Game Wrap-up Show

What do snowboarding, figure skating, and gymnastics have to do with space? Astronauts inside the International Space Station can perform the same aerials and spins with one big exception. Astronauts do not have to stop their aerials. Because of microgravity, they don't have to land snowboards and rebuild momentum for more aerial tricks. They can keep going and going until they bump a wall or another astronaut, or until someone at Mission Control on Earth radios, "Alright, we're impressed. Get back to work."

In space, aerials work like this. You move to the middle of one of the ISS modules so you are not touching anything. You may need help to do this because drifting is common. Then, you start twisting, waving your arms, and kicking your legs. Away you go. Like the snowboarder, stop the flailing and you stop the maneuvers. Guess what? You are still in the same place inside the module. In all that movement, you failed to do one thing. You didn't exert a force on anything. To change your place, you need to apply Newton's Third Law of Motion (action/reaction).

Astronaut Peggy Whitson using Newton's Third Law of Motion to fly through the Destiny module on the ISS.

To get around the ISS, astronauts push against the walls, floor, or ceiling to create an action force. Their bodies respond with an equal reaction force in the opposite direction. Because of center of mass, it takes a little practice for new astronauts to do this right. If you don't push in a straight line with your center of mass, instead of going where you want to, you will rotate around the center with a few head bumps and feet in the faces of your fellow astronauts. (By the way, this can start great spins that can go on for minutes or until you get queasy.)

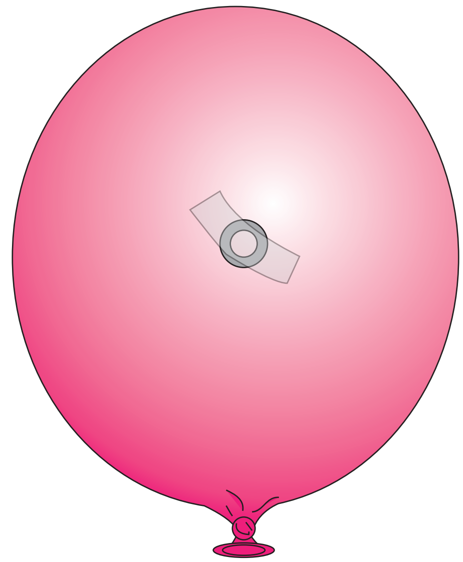
On spacewalks, moving is trickier. One of the first astronauts to discover this was Edward White, Jr. during the Gemini 4 mission in 1965. White carried a small gas gun on his spacewalk. He was attached to the spacecraft with a long tether and oxygen line. When he drifted away from the capsule, he had nothing to push on to get back. He could, of course, tug on the tether to get back but NASA wanted him to try the gas gun. The gun had three nozzles and by pulling a trigger, jets of gas propelled him from one end of the tether line to the other. He exerted an action/reaction force with the gas jets.

Today, spacewalkers still have gas jets to propel themselves. The jets are attached to their backpacks and only used if they get loose from the station. The jets can push them back to safety. Most of the time, they move about by grasping handles (handholds) attached to the outside of space structures. They pull themselves from handhold to handhold to move about. Newton's laws are still at work. They pull on a handhold (action) and their bodies move (reaction).

Back to Ed White's spacewalk. White quickly found out that his gas gun was tricky to use. If he wasn't careful, just pointing the gun and firing some gas would cause him to tumble. The secret was to hold the gun in direct line with his center of mass. Then, he could travel in the desired direction.

Find out about the flight challenges of center of mass by making and testing a "crazy balloon."

Crazy Balloons



Objectives:
Students will:
- manipulate the center of mass of an inflated balloon by taping 1-3 metal washers on its outside
- create and play simulated microgravity sports with a crazy balloon

Preparation:
Obtain uninflated latex balloons. Helium-quality balloons are the most rugged.

Materials:
- Nine-inch helium quality balloons availble at party goods stores (two for every group of two or three students)
- Three metal washers (1/2 or 5/8 inch flat)
- Cellophane tape
- Balloon pumps (optional)

Management Tips:
Organize students into teams of two or three. Give each team one balloon. Caution them to be careful with their balloons because they get only one spare. While balloon pumps are optional, they make blowing up the balloon easier and more sanitary. Check the washers to make sure there aren't any burrs or sharp edges that could puncture the balloon. Encourage students to attach and test one washer at a time until they achieve an interesting flight.

Procedure: Crazy Balloon Sports
1. Have students blow up and tie their balloons.
2. Using tape, have students affix one washer to the outside of their balloons at a random location.
3. Test fly the balloons by gently slapping them upward with an open hand. Watch how the balloon flies.
4. Add up to two additional washers and test fly again. The second and third washers can be in the same or different places.
5. In a class discussion, have students propose a sport to be played with the crazy balloons.
6. By class vote, pick one of the sport ideas and play it in the classroom, using rules students create.

In case students need a little prodding, you might drop hints about sports that could work in the classroom. Here are a couple of ideas:
- A string stretched from side to side across the room and above head level, could serve as the net for crazy balloon volleyball. Clear the floor and have teams sit on the floor to play the game.
- Have students sit on the floor in two parallel lines and conduct a relay race where each student in the line must tap the balloon to the next until it reaches the last person.

Assessment:

Collect student sheets.

Have students write short paragraphs describing the flight of their crazy balloon and explaining its aerial antics. Hold a class discussion to compare descriptions and explanations.

Discussion Questions:

Why does an inflated balloon fall more slowly to the floor than an uninflated balloon?

While the addition of air inside the balloon increases the balloon's mass by a few grams, its increased diameter causes it to be more affected by air resistance than a smaller uninflated balloon. As the balloon falls, air has to move out of the way. The inflated balloon has to push more air out of the way and encounters more force than an uninflated balloon with washers attached. The inflated balloon thus falls more slowly. In microgravity, balloons won't fall to the floor; these balloons will. Tapping the balloons will cause them to float across the inside of the space station. Air resistance and the placement of washers still cause erratic flights.

Why does the weighted balloon fall with crazy maneuvers?

Placing one or more washers on the outside of the balloon moves the balloon's center of mass from the very center of the balloon (without washers attached) to one of its sides. When falling, air resistance affects the unweighted side more than the weighted side. The balloon turns so that the heavy side is downward.

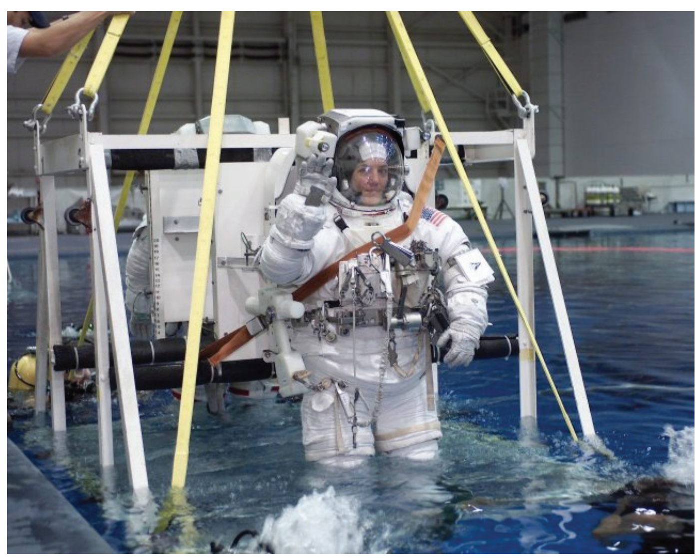
How many washers on the balloon create the craziest flights? Explain.

Just one washer produces the craziest flights. Two or three washers will make the balloon fall faster and turn the balloon faster so that the heavy side is down and the balloon falls straight.

Extensions:

- Obtain helium-filled balloons for each team. Attach strings to each balloon and have students anchor them to their tables. Challenge the teams to create a neutrally buoyant helium balloon. Neutrally buoyant means that the balloon neither rises to the ceiling or falls to the floor. Instead, it floats at the same elevation. Provide tape and weights, such as small paperclips, plastic straws, file cards, etc. When the balloons have been weighted to achieve neutral buoyancy, hold a floating contest. Release the strings and see which balloon stays aloft the longest without touching the ceiling or floor.

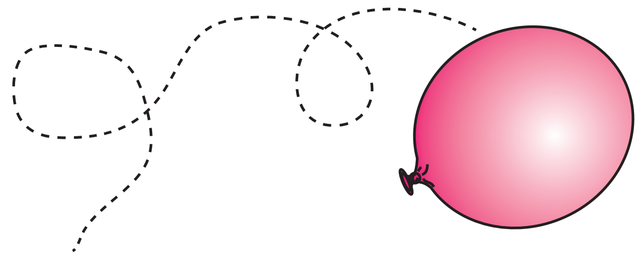
  Adding weights to the balloons is similar to what NASA engineers do when helping astronauts train for spacewalks. The astronaut dons a spacesuit, and weights are added around the outside. Then, the astronaut is immersed in a giant water tank. If the weights are placed correctly about the astronaut's center of mass, the astronaut will neither sink nor rise in the water (neutrally buoyant) and will float right side up or down, allowing the astronaut to simulate microgravity.



Astronaut Heidemarie Piper is lowered into the neutral buoyancy pool for training at Johnson Space Center. Neutral buoyancy is a useful way of simulating microgravity for astronaut training.

Crazy Balloon Championship Name: ___________________

Welcome to the first annual Crazy Balloon Championship! Pick your team and get ready to compete. First, you have to design your crazy balloon and create a sporting event to go with it.



Instructions:

1. Inflate and tie a round balloon.
2. Using cellophane tape, attach a single metal washer to the outside of the balloon.
3. Test fly your crazy balloon by giving it an upward pat and see what it does. Describe its flight.

Why did the balloon fly that way?

4. Add another washer and fly it again. What did it do?

5. Add one more washer and test it again. What did it do?

6. Select the best flight characteristics of your crazy balloon. It might fly best with just one or two washers.

7. With your teammates, invent a sport to play with your crazy balloon. What is the objective of your sport? What are the rules? Develop a presentation you can make to your class explaining your sport. The class will decide which sport is the best and try it out! (Use the back of this sheet if you need more space.)

Name of your sport ___________________________________

Rules:

Javelin Rockets

Pre-game Talk Show

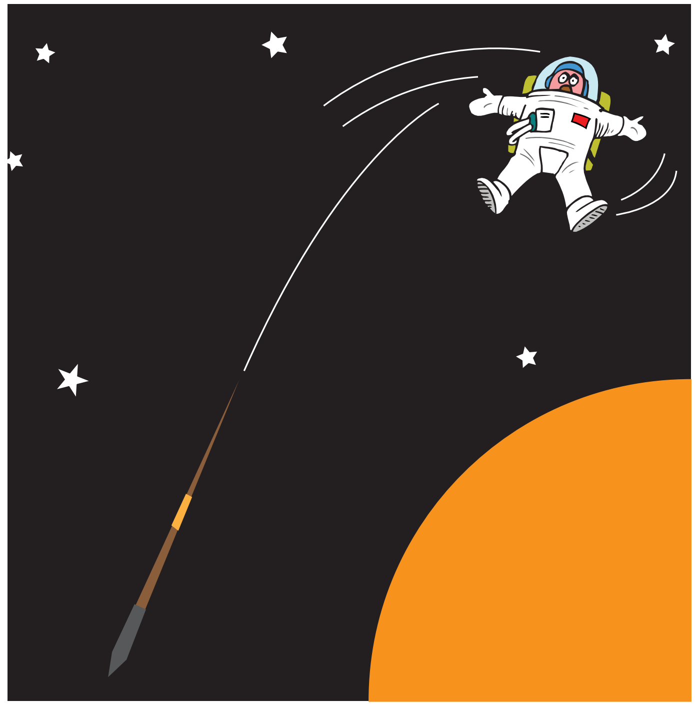
Welcome to the 2038 Solar System Olympics. Today's events include the ever-popular Javelin Rockets. Our interplanetary teams are readying their rockets and fine-tuning their guidance systems. It should be a great event.

We have a few minutes before the event begins. Let's look back at the roots of this exciting competition.

The first Olympic competition is said to have been held in ancient Greece in the year 776 B.C. Those ancient games featured running, jumping, wrestling, discus and javelin throwing. The original javelin was a throwing spear used in battles. Soldiers had to throw spears accurately or their enemies could throw them back. This led to the popular javelin throwing event at the Olympics. The object of the event is to throw the javelin the farthest.

In the terrestrial Olympics, javelins for men are sticks that are about 2.6 meters long and have a mass of about 800 grams (8.5 feet, 1.75 pounds). Javelins for women are 2.2 meters long and 600 grams in mass (7.2 feet, 1.3 pounds). The center of mass for

Over 900 years ago, the first Chinese rockets were really rocket-powered spears (javelins).



the javelin is about a meter from the tip. That means that the front end of the javelin is slightly heavier than the back end. This helps provide stability in flight. With the javelin flying true and not wobbling, air friction is reduced and the distance the javelin can travel is greater. If you didn't know better, you would think we were not talking sports but talking science. Well, we are talking science. Sports is mostly science in action.

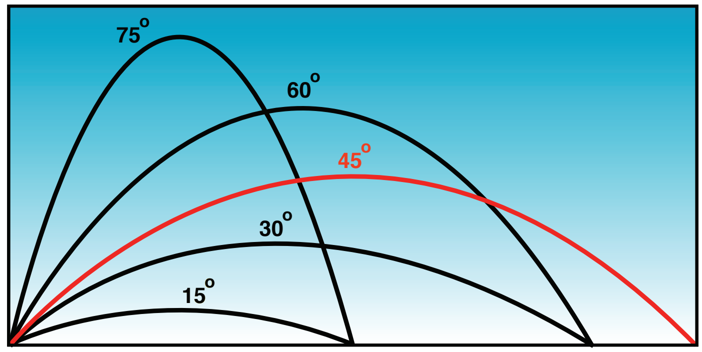
Consider again the javelin's center of mass. As we learned earlier, all objects in flight tend to rotate around their centers of mass. Astronauts quickly discover this when they push off the wall of the International Space Station. A javelin with its center of mass in the very middle of the shaft will tumble or wobble when it is thrown. However, when the center of mass is moved toward the front end, it will fly true without wobbling and achieve the longest distance.

The reason for a javelin's true flight is the same reason a rocket flies true. Rockets have fins at their back ends. As long as they fly straight, the fins provide little friction, or drag, with the air. However, if the rocket begins fishtailing or wobbling from side to side, drag on the fins increases. Drag from the air exerts a force on the fins, turning them so that the rocket flies true again. It works the same way with javelins. They don't have fins but their lighter back ends stabilize the flight. Fins work better, but the principle is the same.

Another thing to know about the flight of a javelin or rockets is that the trajectory, or flight path, of both is curved. That's because of gravity. Inside the International Space Station, astronauts appear to move in straight lines. A push against the back wall of a module sends them straight down the middle to the other end. At least, their flight looks straight. It's really curved. The reason it looks straight is that the ISS is traveling on a curved orbit around Earth. If someone on the outside could watch you move down the module, that observer would see that you and the ISS are following curved paths together. It just looks like you are traveling straight when you're inside.

Let's go back to our Solar System Olympics. The javelin rocket event is about to start. Competing teams will be aiming their rockets at targets. They have to remember that gravity will affect the flight of their javelin rockets. That means they have to aim above the target so that gravity will curve the javelin rocket's flight right into the bull's-eye. How high they aim above the target depends upon how fast the rocket goes. Fast rockets arrive quickly, so gravity doesn't have much time to curve their paths. Slower rockets have bigger curves. The trick is to select the right launch angle for your javelin rocket's speed.

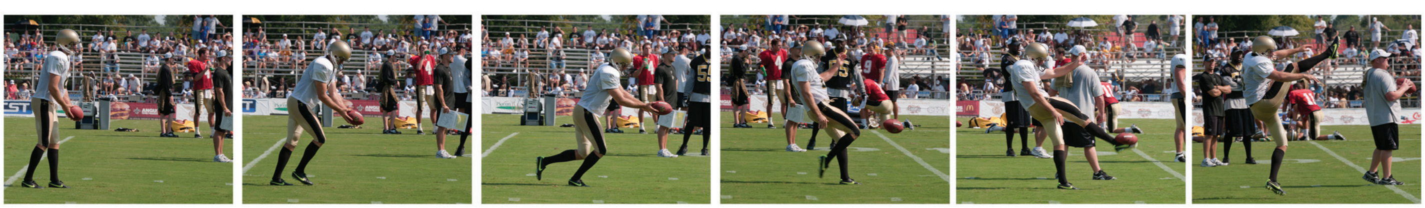
Long ago on Earth, soldiers and Olympic javelin throwers understood the relationship between the speed of a javelin and the throwing angle. Look at the chart below. It shows five different javelin throws. If the javelin is given the same speed each time, the longest throw is achieved if the javelin is thrown at a 45 degree angle.



The arcs above reflect the flight of five javelins thrown with the same force. Gravity bends the javelin path. The difference in the flights is caused by the different launch angles.

The same applies for javelins thrown on the moon or Mars. The gravity of these two bodies will curve the javelin flight. However, gravity on the moon or Mars is considerably less than on Earth. The moon's gravity is only one-sixth that of Earth, and Mars' gravity is about two-fifths that of Earth. That means javelins will travel much farther if thrown with the same force and angle as on Earth.

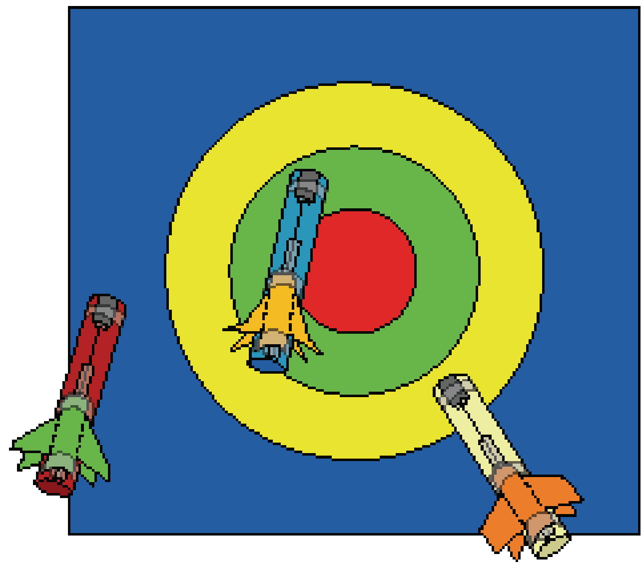
The competition is starting. Competitors are aiming their rockets toward the targets. When ready, a blast of air will send the javelin rockets flying.



Thomas Morstead, punter for the Super Bowl Champion New Orleans Saints, employs the same science as a javelin thrower. Morstead has to judge precisely the angle of his punt to determine hangtime and distance. How far do you think his punts would travel on the Moon, or on Mars? Which of Newton's Laws is at work here?

Javelin Rockets

Objectives:
Students will:
- construct and fly paper rockets with Velcro-covered nose cones
- investigate launch angle versus distance with their rockets
- compete in a rocket javelin sports event



Preparation:
Obtain and cut 15-inch lengths of 1/2” PVC pipes, one for each student. See Page 13 for information on how to cut PVC. A PVC cutter from hardware stores is recomended but a fine-tooth saw and sandpaper will work as well. Also, prepare a felt target.

Materials: Per student or group
- 15-inch lengths of 1/2-inch PVC pipe (One per student)
- One rocket pattern on copy machine paper per student
- Scissors
- Cellophane tape
- Rulers
- Felt target (see instructions below)
- Two- to three-inch Velcro strips (adhesive or Velcro for sewing can be used)
- Marker pens or crayons for decorating rockets (optional)
- Meter stick or tape measure for measuring flight distances
- 12 inches of string or thread
- Small metal washer or nut

Management Tips:
Students will use the PVC pipe as construction forms for building their rockets. They will also use the pipe for launching their rockets by blowing through the end. Because of the low cost of PVC pipe, it is recommended that one pipe segment should be made for each student with their names written on them. Otherwise, pipes will have to be disinfected with a good cleansing and sanitizing agent between uses.

Some students may have trouble generating enough wind power to launch their rockets. Have them practice blowing through the pipes. Tell them to inflate their cheeks with lips closed to build up pressure inside their mouths, then sharply puff through the tube.

An alternative to students blowing through the pipes is to construct several “Pop! Rocket Launchers.” The launcher employs a 2-liter soft drink bottle as the pressure chamber, and students stomp on the bottle to force air through a PVC pipe to launch their rocket. The guide for constructing the launchers can be downloaded from the following NASA site:

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Rockets.html

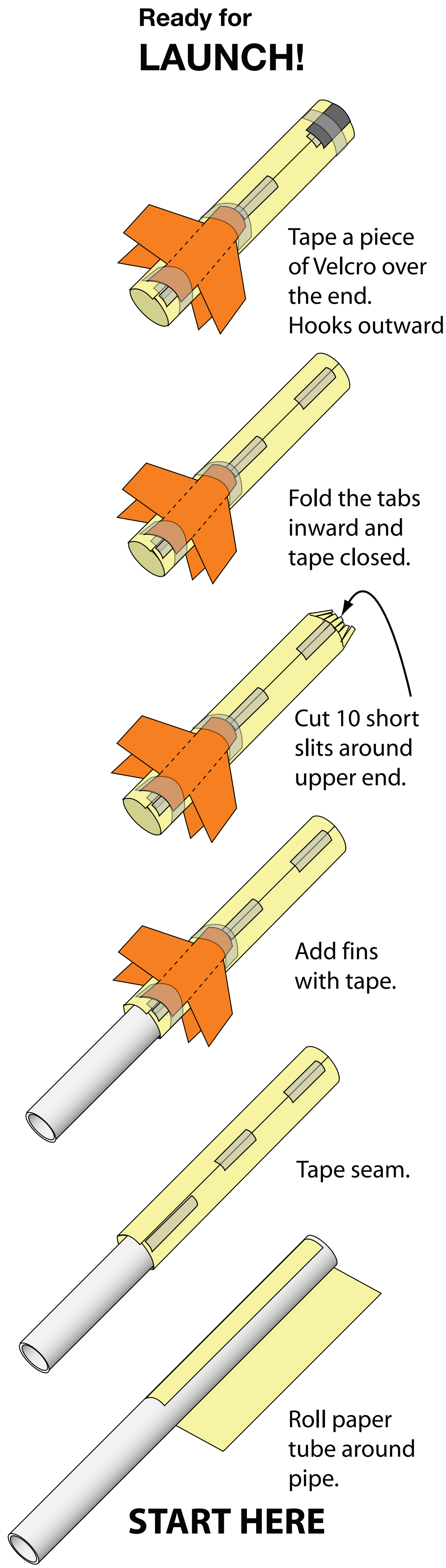
Have students practice launching their rockets at different angles in an open space, such as a gym or cafeteria or outside. Let them discover the relationship between angle and distance. After students have explored launching their rockets informally, have students diagram what happens at different trajectories. Discuss their conclusions and other factors that might affect the flight of their javelins and then start the rocket javelin competition.

Making the Target

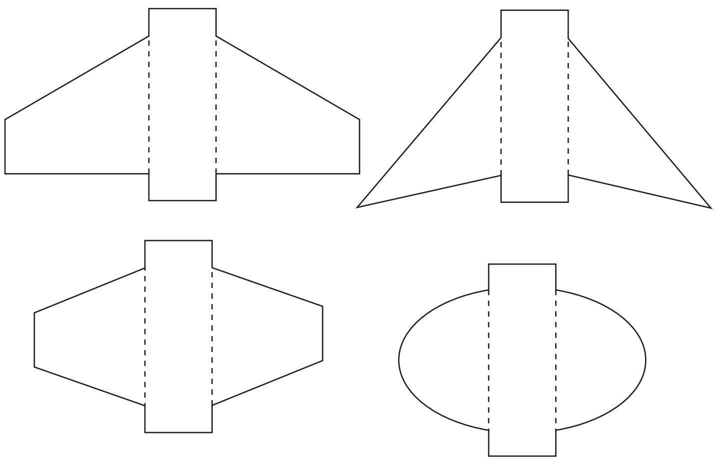
Obtain a large piece of felt from a fabric store. Felt is available in 72-inch bolts. Buy some smaller pieces of different colors for making the rings. Use fabric glue or stitching to hold the rings and bull's-eye in place. Mount the target loosely against a wall. Allowing the target to hang free provides some cushioning for the rockets and better gripping of the Velcro.

Procedure: Building javelin rockets

1. Set up a supply area for paper and tools.
2. Review the procedure for making javelin rockets. The diagram to the right shows the construction steps.
3. Have students cut their sheets of paper in half across the middle to make two sheets 8.5 by 5.5 inches in size. One sheet will be used to roll the rocket body, and the other will be used for making rocket fins.
4. Encourage students to design their own fins. Shapes for fin ideas are shown. The rectangular shape between the different fin shapes has been scaled and does not match the paper tube.
5. Conduct a preflight checkout. Make sure that the front end of the rocket is closed and that the Velcro is mounted securely with cellophane tape across the nose cone. If you are using adhesive-backed Velcro, it may not be necessary to use tape as well, but tape will help the Velcro stay in place.
6. Select an open area to test the rocket javelins. Caution students about aiming their rockets. They must not shoot their rockets at each other. Set up a firing line behind which all students must stand. Remind students to take notes on their data sheets. After all rockets have been fired, students may retrieve them. Remind students to try different launch angles and compare the angles to the distances the rockets fly.
7. Allow students to modify the fins on their rockets. They may wish to reduce their size or change their shape.
8. When all students are proficient with their rockets, then it is time to hold the javelin rocket event. Have students create the basic rules (e.g., how far away the target is, a point



Ideas for rocket fin shapes



(Not drawn to scale.)

scoring system, how many tries per person, etc.).

9. Hold the javelin rocket event and have the winners share their secrets - design of their rocket, aiming strategy, etc.

Assessment:

Collect student data sheets.

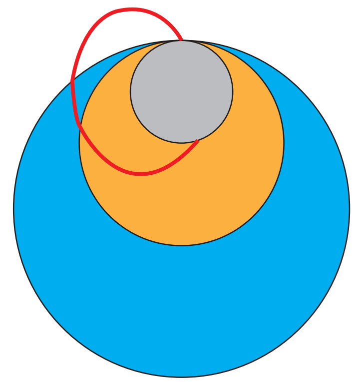
Discussion Questions:

Is there a relationship between the launch angle and the distance the rockets flew? Explain.

Assuming students used the same force to launch their rockets each time, the answer is yes. Through trial and error, rockets launched at a 45-degree angle will fly the farthest. Rockets launched at a lower angle will be drawn to the floor by gravity before they have gone very far. Rockets launched at a higher angle will use up some of their momentum opposing gravity and will land closer to the launch site.

Will rockets travel farther across the surface of the moon or Mars if the same launch force is used? Explain.

Yes. There are three reasons for this. First, the rockets will fall more slowly on the moon or Mars because their gravity is not as strong as Earth's. Second, both bodies are much smaller than Earth. Although each is round, the curvature of Earth is flatter than that of the moon or Mars. A well-launched rocket javelin on the moon or Mars will fly over the horizon and have farther to go before hitting the surface. Third, the moon doesn't have an atmosphere and the atmosphere of Mars is about 1/100 the density of Earth's atmosphere, at sea level. With little or no atmosphere, atmospheric drag is eliminated and greater distances are possible.



The same rocket flight is shown for Earth, Mars, and the Moon. Because of different diameters, the rocket will hit Earth's surface at a shorter distance from the launch site than it would on Mars or the Moon.

If rocket javelins were flown inside the International Space Station, how would they be aimed to hit the target? Explain.

The ISS and astronauts inside it are traveling together on a curved path that enables them to orbit the Earth. Because of this, a rocket javelin launched down the length of the ISS modules would appear to travel in a straight line. This requires a mental adjustment. On Earth, rocket javelins have to be aimed above the target because gravity causes the rocket to fall towards the ground. With just the right direction and speed, the rocket arcs to the target. In orbit, the illusion of traveling in a straight line means that you have to aim directly at the target.

Extensions:

- Challenge students to design a throwing game for the International Space Station. What is the object of the game? What will be used to make the game equipment? How could the game be made safe so it wouldn't hurt anyone or damage equipment in the ISS modules? Should a target be mounted or free-floating? Etc.

Javeline Rocket

Name: ____________________

1. Design and build your javelin rocket .

2. Follow the steps provided by your teacher to make the rocket body.

   This is the long tube. One end of the tube will be closed off with tape and a Velcro strip will be taped over that end.

3. Decide what kinds of rocket fins you want your javelin rocket to have.

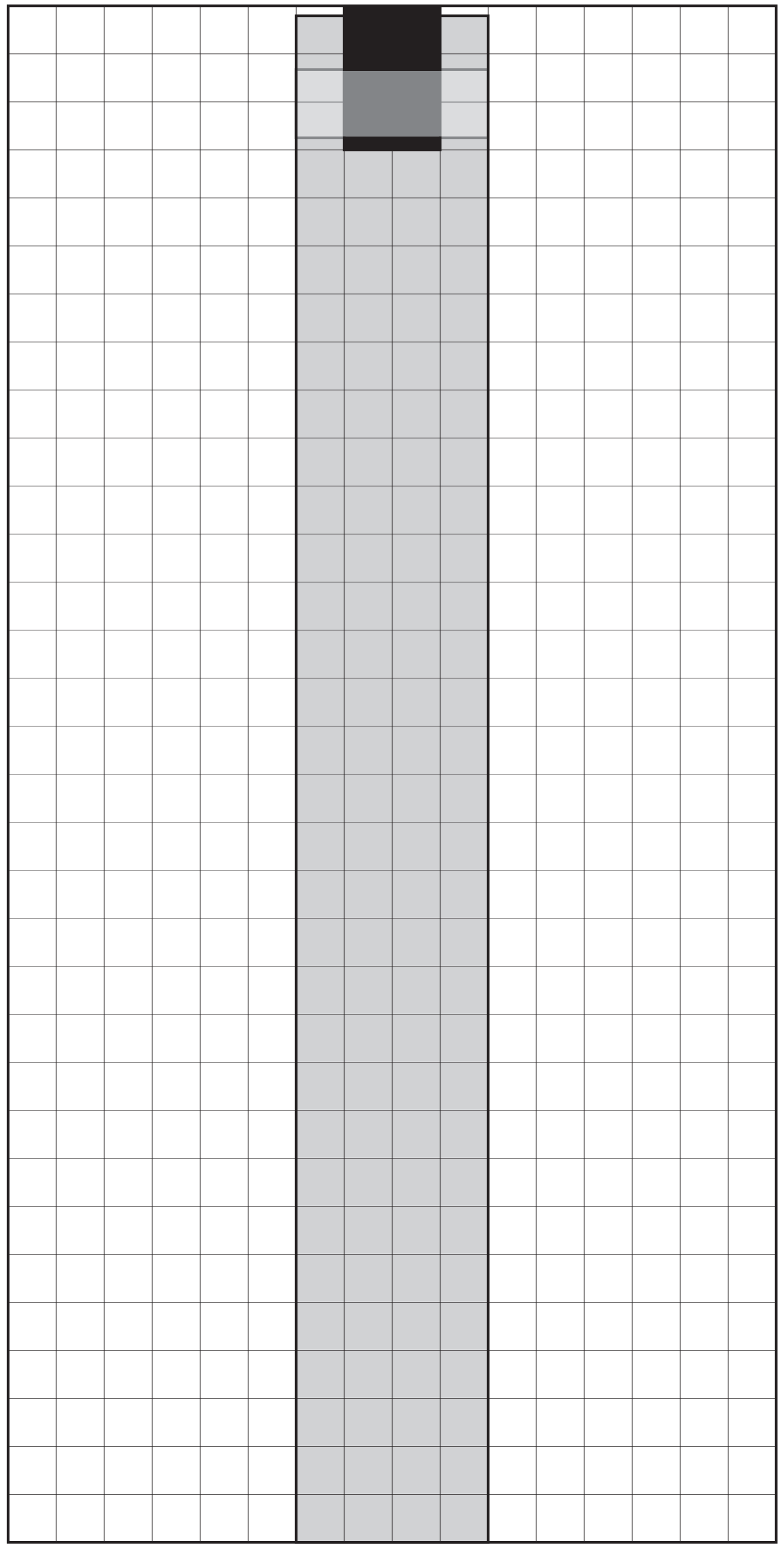
   Draw a picture of what you want them to look like.

4. Make your fins and tape them to the lower end of the rocket.

   If you want to change the shape of the fins, use the scissors to trim them.

Your rocket is ready to fly!

Front end of Javelin Rocket with Velcro held with tape.



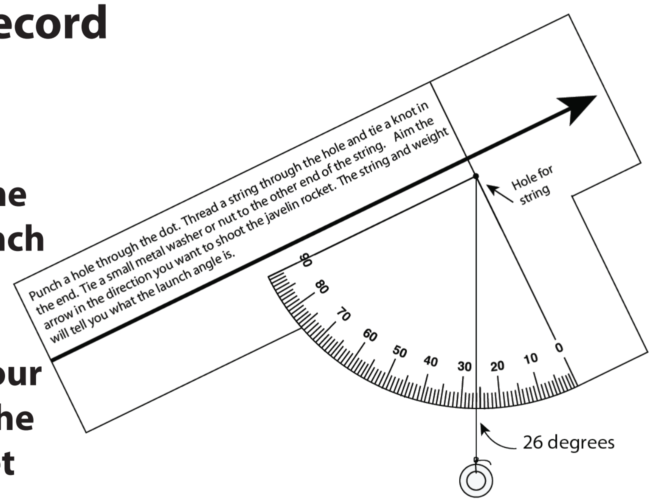
Fins go on this end of the rocket.

Javeline Rocket

Name: ____________________

Practice Record

Test Flights - Launch Angle and Distance



Launch your rocket several times. Use the same amount of force each time. Estimate your launch angle using the quadrant sighting device.

Write the angle below and measure how far your rocket traveled. Measure to the point where the rocket hit the floor and not to where the rocket slides or bounces to.

Which launch angle worked best?

Launch Angle	Flight Distance

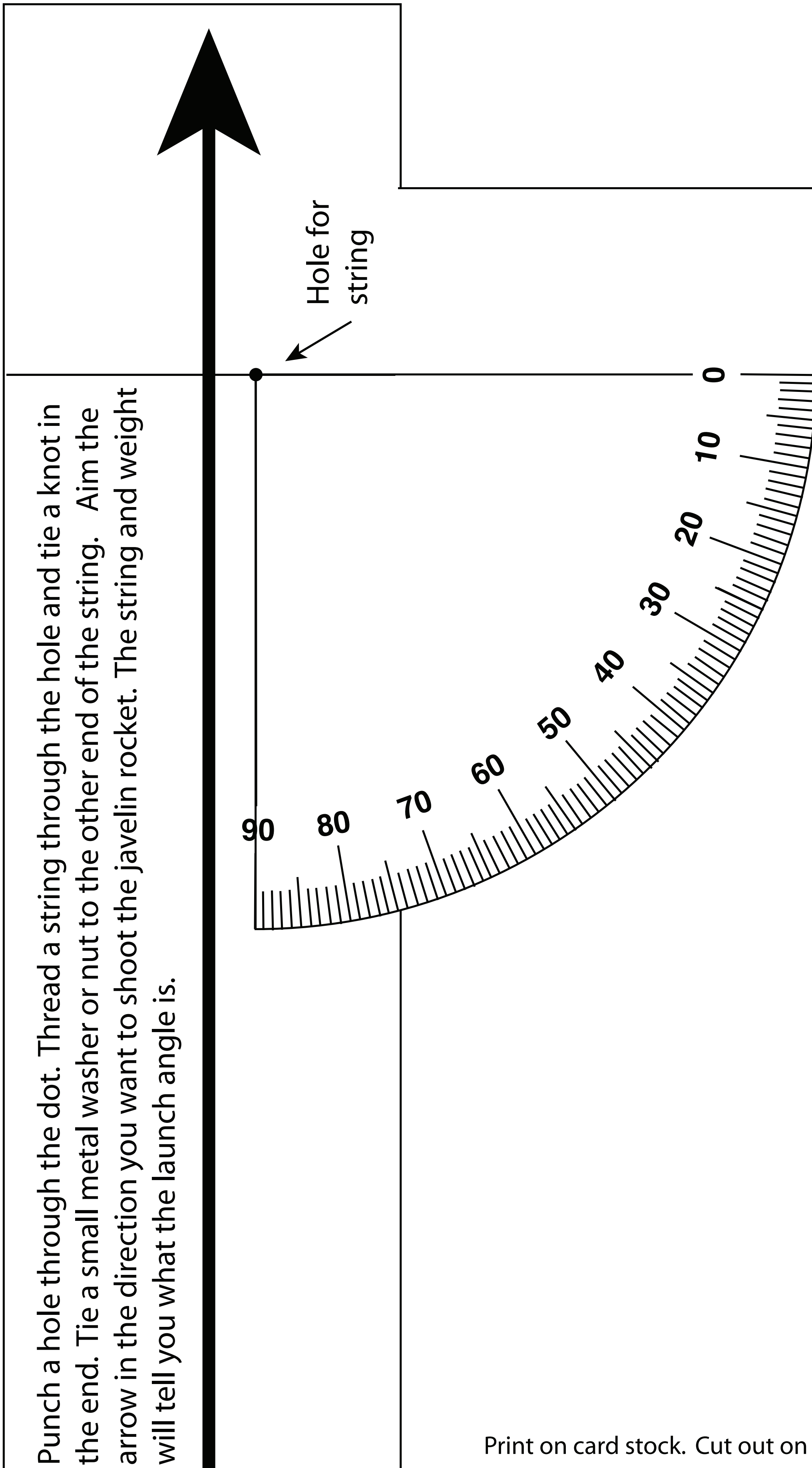
Using the space below, describe how your rocket flew. (straight, curved, spun, etc.)
Did you do anything to make it fly better?

Javelin Rocket Competition Record

Try to hit the target with your javelin rocket . Use your practice flights to determine which launch angle will send your rocket to the bulls-eye.

Use the space below to describe your results.
(on target, dead center, missed, close, etc.)

Sighting Quadrant for Javelin Rocket



Print on card stock. Cut out on solid lines.

Slam, Bam, Crash

Halftime Talk Show

"Well folks, this has been one amazing game. We've seen player after player carried off the field - torn ligaments, groin injuries, broken bones, dislocated shoulders. It's been real carnage out there! Let's ask my co-host. Have you ever seen a game this rough?"

"Not often, John. This has been a hard game. You get that when there's a championship at stake. Even with all the protective gear, players get hurt."

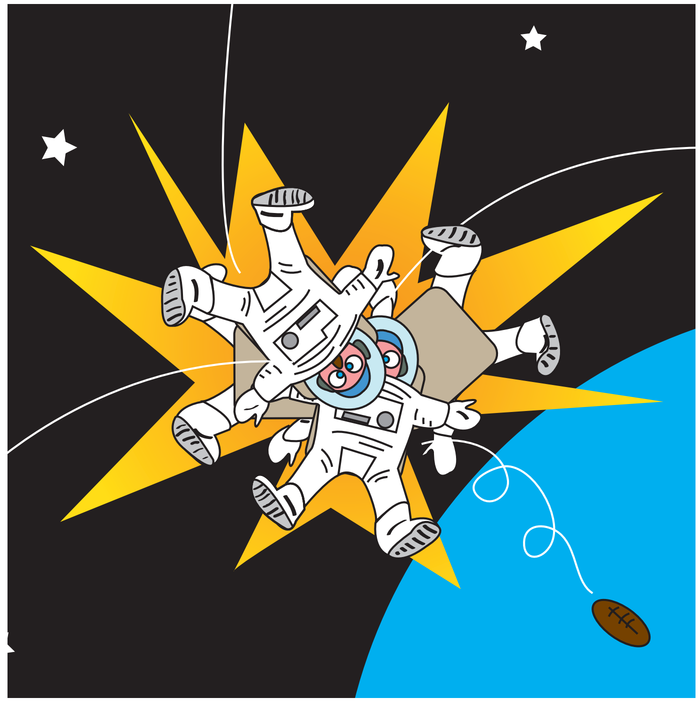
"Why is that, Maria?"

"Actually, it's quite simple. My old science teacher explained it. More than 300 years ago, the English scientist Isaac Newton came up with the Laws of Motion. In particular, his first law talks about how an object at rest stays at rest or an object in motion stays in motion unless acted upon by an unbalanced force."

"Oh yeah. I remember that. It's also called the Law of Inertia."

"Right you are John. Well, it works like this: You get your running back heading down the field with the ball at a speed of 10 or 12 miles per hour. At the same time, defensive linemen from the other team target the runner

Newton's Second Law of Motion is about to be tested as New Orleans Saints linemen use their combined inertia to block the accelerating mass of the other team.



from a couple of directions. All told, there might be a thousand pounds of high-speed muscle converging. Then, wham! They all go down in a pile."

"That must really hurt!"

"Oh boy, does it! The amount of inertia each player brings to the pile is called momentum."

"Maria, are you saying that momentum is just inertia in motion?"

"Right, John. We measure it by multiplying mass times velocity. In other words, the more mass the running back has and the faster he is running, the greater the momentum. In other words, the harder it is to stop him."

"Does that mean the faster you bring the running back down, the more the force is concentrated?"

"You got it! A faster stop hurts more."

"Maria, thanks for the explanation. Folks, you heard it. Momentum is inertia in motion. So, here's the problem. You can stop an object, but how fast you stop it is the key. Well, the game is about to start up again. Hey, I wonder what it would be like to play football in space. I bet spacesuits would need a lot of extra padding."

Stopping - Fast or Slow?

Imagine driving a car down a hill and the brakes fail. You have a choice - crash into a brick wall or into a haystack. Which will you pick? The haystack should be your choice because hitting a haystack will slow you to a stop. Hitting the brick wall means an instant stop. Stretching the time it takes to come to a stop reduces the force felt on the car and by the driver inside. With the haystack, you will probably survive, but it's all over with the brick wall!

This same idea applies to astronauts in space. On a spacewalk, they might have to pick up a big satellite and move it so it can be repaired. Although the astronauts can't feel the satellite's weight, they have to remember that it has mass. If they give it a good shove, the satellite will gain lots of momentum, which can cause real damage if it smacks the shuttle

Helmets and shoulder, thigh, knee, arm, and hip pads offset the massive forces produced when New Orleans Saints players slam, bam, and crash into their opponents.

payload bay wall. For safety, everything is done in slow motion in order to keep momentum under control and to make stopping easier.

The design of protective sports gear follows this same approach. For example, a football helmet has a hard shell, but there is padding under the shell. When a player's head takes a hit, the momentum of the player's head tries to carry it in the same direction it

During the 1992 STS-49 space shuttle mission, three spacewalkers caught an errant INTELSAT satellite by hand because a mechanical capture tool didn't work. The spacewalkers had to maneuver the massive satellite very slowly into the payload bay and not give it additional momentum that could cause it to bump and damage something. The satellite was later fitted with a new booster rocket and sent into its proper orbit.

was going before the hit. The result is that the player's head will smack hard into whatever got in its way (another player or the ground). Here's where the padding comes in to play. The padding compresses under the force of the hit and slows the impact so that it is more like hitting a haystack than a brick wall.

Here's another way to look at it. Momentum is mass times velocity.

$$Momentum = m \times v$$

In order to stop an object, Newton's First Law of Motion states that an unbalanced force will have to be exerted on the object. How much force depends on how long the force is exerted. We can rewrite the momentum equation slightly by adding force and time.

Force times time = mass times velocity.

$$f \times t = m \times v$$

Let's go back to the brick wall and the haystack. Crash a car into a brick wall. Because stopping is almost instantaneous, time in the equation is very short. To keep the equation in balance, the force has to be greater. We will illustrate the increased force with a larger letter and the time with a smaller letter.

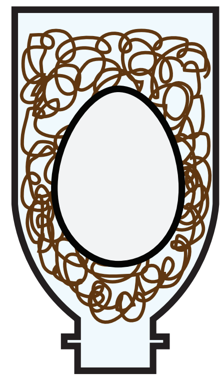
$$\Large f \normalsize \times \ \small t \normalsize = m \times v$$

A haystack crash with the same vehicle traveling at the same velocity has a different result. The haystack slows the stop more gradually, increasing the time while reducing the force. The equation looks like this.

$$\small f \normalsize \times \Large t \normalsize = m \times v$$

The difference in the two crashes is the effect on the car and the passengers inside. The haystack crash takes longer, and the impact forces are less as a result. (If you are about to crash your car, pick the haystack!) It's the same with protective athletic gear. Padding slows the impact.

Space Helmet Challenge



Objectives:

Students will:

- design and construct padded space helmet prototypes for egg astronauts (eggstronauts)
- test and evaluate the effectiveness of their eggstronaut prototype helmets

Preparation:

Construct the helmet tester using the instructions below. Gather various materials that student teams can use for their helmet designs. Conduct the Egg Drop Inertia Demonstration described below. Discuss the questions associated with the demonstration as an introduction to the activity.

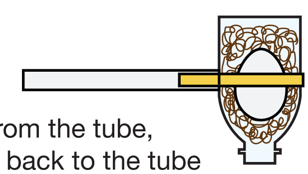
Materials:

- Several empty two-liter soft drink bottles
- Empty 1/2-liter water bottles for each team
- Empty copy machine paper box and lid
- A two-foot length of 1/2-inch PVC pipe from hardware store
- Duct tape
- Marble that fits the inside the PVC pipe
- Roll of toilet paper
- Medium or small eggs
- Plastic wrap or zip-type sandwich bags
- Various packing materials such as:
  Cotton balls
  Tissue
  Rubberbands
  Sponge or foam
  Packing "peanuts"
- Scissors
- Masking tap
- Beam balance or electronic scale
- Eye protection

Management Tips:

Cut the 1/2-liter water bottles for the teams. Recycle the bottoms and caps. Have students work in small teams. Make sure each team wraps its egg in cellophane or seals it in a sandwich bag before designing the padding system for their helmets. Doing so will greatly reduce the possibility of a mess if the helmet design fails. Tell teams that the cut water bottle will serve as the space helmet shell for their tests. When doing the tests, the box lid can be secured with masking tape or held down with a heavy book. Make sure no one is down range of the box in case the projectile misses the test helmet and penetrates the box wall. Appoint one student to be a "range safety officer" to check for goggles and a clear test zone.

If students have an aiming problem and the marbles glance off their helmets, a piece of masking tape applied to one side of the tube, wrapped around the bottle, and secured to the other side of the tube will keep the tube aimed at the center of the helmet.



Masking tape applied from the tube, around the helmet, and back to the tube will keep the tester aimed properly.

Egg Drop Inertia Demonstration

According to Newton's First Law of Motion, objects at rest or objects in motion have the property of inertia, which causes them to resist changes in motion. When a car crashes into a brick wall, the momentum of the car (inertia in motion) causes it to crumple. The same result occurs if the car is not moving but is struck by a moving object, like a big truck hitting it head-on.

To show how inertia causes objects to resist changes in motion, set up the following materials as shown:

Glass of water
Aluminum pie tin
Cardboard tube from toilet paper roll
Egg

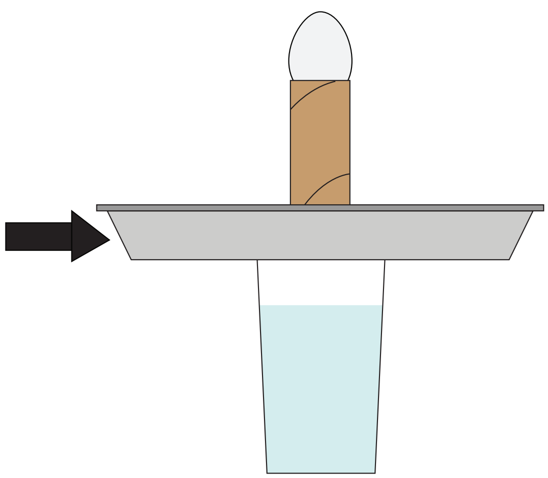
Using a motion similar to swinging a tennis racket, strike the edge of the pie tin with your hand and carry your swing completely past the egg. The impact will remove both the pie tin and the paper tube from under the egg. The inertia of the egg will cause it to resist that motion. Instead, gravity will cause it to drop into the water in the glass.

Why did the egg remain behind?

Inertia

What would happen if you struck the egg directly?

The impact force and the egg's inertia would cause it to break.



Constructing and Using the Helmet Tester

Insert the PVC pipe into the 2-liter bottle and tape it in place with duct or masking tape. Save the extra 2-liter bottles for spares if the primary tester bottle is damaged.

Cut a hole just large enough to insert the pipe into the box through one of its ends. Place a few books or a small box under the pipe for support. A short segment from the center tube or a roll of toilet paper, hot-glued to the box bottom, will enable helmets to be positioned in the same place for each test.

To use the tester, a single square of toilet tissue is inserted into the pipe, followed by the projectile (marble). Using a pencil like a ramrod, push the projectile part way into the tube. Insert the tube into the box hole. Place the prepared helmet test article in direct line with the pipe. While one student anchors the pipe by holding it down on the support books, another student stomps hard on the bottle where the label is located. Doing so produces a strong force that propels the projectile into the helmet test article. Open the box and observe the results. Blow through the tube to reinflate the bottle.

Procedure

1. Divide students into small teams and challenge them to design protective head gear to be worn by spacewalkers. The headgear, some sort of padding system, will be worn inside a space helmet.
2. Provide each team with the upper half (spout end) of a 1/2-liter plastic water bottle and an egg. This represents the spacesuit helmet. Also, provide a variety of materials that can be used for protecting the egg. Tell the teams that the protective system they create must fit inside the helmet.
3. Demonstrate the helmet tester with an egg inside a "helmet" without a protection system. Be sure to wrap the egg with cellophane or place it in a sandwich bag. Discuss why the egg broke (inertia caused it

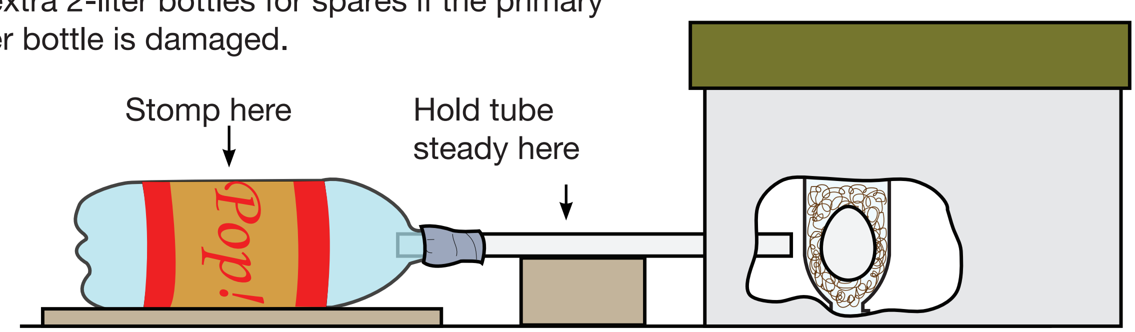


Illustration not drawn to scale

to resist a change in motion and the force of the projectile broke the shell).

4. Discuss ways of increasing the force of the projectile impact (stomp harder, use heavier projectile, make the tip of the projectile more pointed, etc.).
5. Remind students to evaluate the results of their protective system test and record their observations on their student pages.

Assessment:

Collect team evaluation pages and review their narratives and evaluations of their test results.

Discussion Questions:

Why is inertia important to athletes and spacewalkers?

Many sports injuries are caused by impacts that exceed the strength of muscles and bones. When a player is slammed to the ground or collides with others, inertia converts motion into force. Spacewalkers are trained to move slowly so they do not build up momentum that can cause injury or damage when bumping a more massive object, such as the International Space Station.

Explain the expression "The bigger they are, the harder they fall."

This expression has many meanings, but in a physics context, it relates to the force experienced when a person falls or crashes into a massive object. More mass in a person's body means more force that has to be dissipated during the impact. Also, taller people have farther to go to hit the ground, so gravity accelerates them more than shorter people before impact.

How could spacewalkers play football in microgravity?

A microgravity football game would be very difficult because players would not be able to run across a grassy field like they do on Earth. They would have to find some other way of exerting force to propel them forward. A microgravity football game might work if the players had rocket propulsion units. A better place for a football game would be inside a domed stadium on the moon.

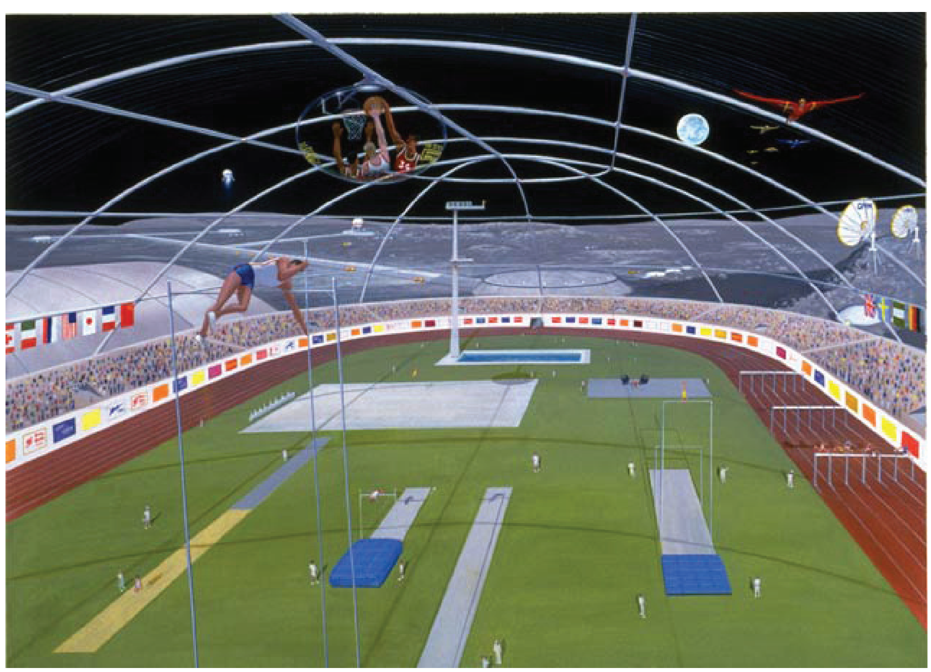
Extensions:

- Have students investigate spacesuit design at the following NASA site:

  http://www.nasa.gov/audience/foreducators/spacesuits/home/index.html

- Challenge students to design a new spacesuit that could be used by space athletes.

"Leap of Faith" by Pat Rawlings portrays an Olympic stadium on the moon.

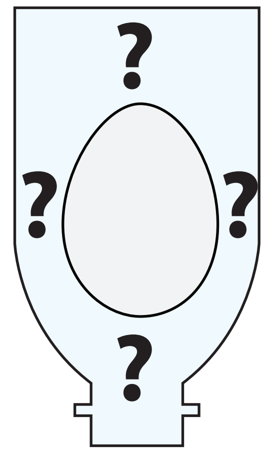


Space Helmet Challenge

Name: ____________________

Working as a team, design, construct, and test a space helmet padding system. The helmet will be used for an eggstronaut. You will need the following:

Water bottle (upper half)
Egg
Plastic bag or cellophane
Protective materials of your choice



Basic Instructions:

1. Wrap your egg in a piece of cellophane or seal it inside a plastic bag.
2. Invert the water bottle half and insert the egg.
3. Select materials to protect the egg from impacts and pack them inside the helmet around the egg.
4. Temporarily remove the egg and weigh helmet and padding.
5. Following instructions provided by your teacher, test your helmet.
6. Record your observations before and after your test.
7. Be prepared to report on the results of your test to the rest of the class.

Describe your protective system.

What materials did you use? ______________________________

Why did you pick these materials? ______________________________

____

What was the mass of just the helmet and protective system? ________ **grams**

Do you think your system will protect the eggstronaut? ______________

Describe what happened to the eggstronaut during the test.

____

____

What might you have done differently to improve the performance of your system?

____

____

Using the back of this page, write a short paragraph explaining what inertia is and why it is important in activities like sports and space-walking.

Spaced Out Sports Glossary

The following terms are useful for understanding the concepts and scientific principles featured in this guide:

Acceleration – the rate by which an object changes its velocity with time. (See Velocity.)

Balanced Force – a force acting on an object that exactly balances another force acting on that same object from the opposite direction. (E.g., gravity pulling on you while your muscles and bones act in the opposite direction enabling you to stand.)

Center of Mass – the average position of all of the mass of an object (also called the balance point).

Drag – forces, such as air friction, acting in the opposite direction from the force propelling the object. (E.g., gravity causes a person to fall, but a parachute provides drag that slows the fall to a safe velocity.)

Force – a push or a pull.

Friction – forces that resist the motion of an object through the air or across a surface.

Gravity – the attraction between objects due to their mass.

Inertia – the property of an object that causes it to resist a change in motion.

Mass – the amount of matter contained in an object.

Microgravity – an environment created by freefall in which gravity's effects are greatly reduced.

Moment of Inertia – the principle of inertia applied to rotating objects. (See inertia.)

Momentum – the mass of an object times its velocity (inertia in motion).

Newton's Laws of Motion – Three laws that describe the motion of objects.

1. Objects continue in a state of rest or motion in a straight line unless acted upon by an unbalanced force.
2. The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to the mass of the object.
3. Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

Neutral Buoyancy – a condition of an object in a fluid, such as water, where all the forces on that object are balanced and the object neither rises nor sinks. (E.g., an astronaut in a water tank practicing spacewalks.)

Unbalanced Force – a force acting on an object, that causes it to move (a force not balanced by an opposing equal force).

Velocity – the speed and direction of a moving object